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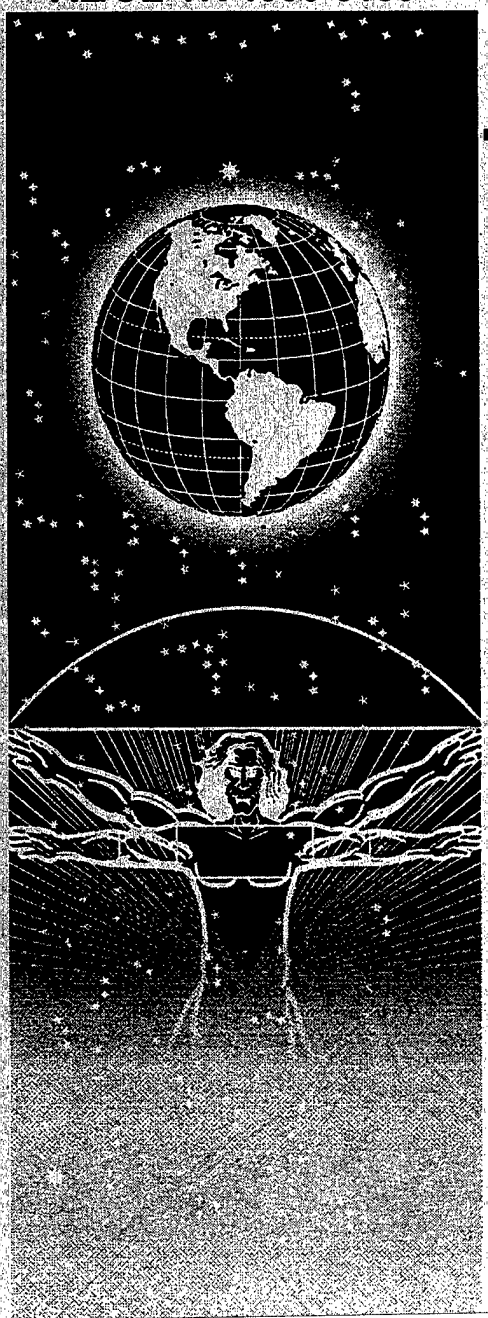

UNITED STATES AIR FORCE ARMSTRONG LABORATORY

Risk Assessment of Polychlorinated Biphenyls (PCBs) On-Board Navy Ships

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December 1996

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

TERRY A. CHILDRESS, Lt Col, USAF, BSC
Director, Toxicology Division
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Shipyard workers and active duty personnel have the potential to be exposed to various congeners of Polychlorinated Biphenyls (PCBs) during operational, maintenance and disposal scenarios. On 6 December 1994 the US Environmental Protection Agency (EPA) proposed a revision of the PCB ruling which would significantly impact Navy O & M costs and limit options for disposal of ships and submarines. The significant drivers to the EPA criteria were assessed. Additional occupational samples were collected to provide a statistically significant data base from which to evaluate possible exposure. No samples were identified with PCB in the vapor phase, therefore, inhalation was not considered a pathway of concern. Dermal exposure was found to be the only potential exposure route. A probabilistic risk assessment was conducted for both shipyard workers and crew members. The level of risk was determined to be acceptable for both active duty and shipyard workers. The approach presented here is applicable for PCB exposure in all three services.

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PREFACE AND ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
ATSDR	Agency for Toxic Substances and Disease Registry
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
DOD	Department of Defense
DOE	Department of Energy
GC	Gas Chromatography
HEPA	High Efficiency Particulate Air
IARC	International Agency for Research on Cancer
IEHR	Institute for Evaluating Health Risks
LADD	Lifetime Average Daily Dose
LOD	Limit of Detection
NAVSEA	Naval Sea Systems Command
NCF	NAVSEA Copy Files
NCI	National Cancer Institute
ND	Non-Detect
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzodioxins
PCDF	Polychlorinated dibenzofurans
PEL	Permissable Exposure Limit
PPE	Personal Protective Equipment
PSNS	Puget Sound Naval Shipyard
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
STEL	Short Term Exposure Limit
TCLP	Toxicity Characteristic Leaching Procedure
TLV	Threshold Limit Value
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average
USEPA	United States Environmental Protection Agency

INTRODUCTION

Background

Older Department of Defense (DOD) systems employed a variety of components which have been identified as containing polychlorinated biphenyls (PCBs) either as contaminants or as part of the formulation. These PCB articles were selected for their performance characteristics including fire retardant properties. The Navy has, for some years, been gathering data on the extent of the distribution of these PCB articles throughout the weapon systems and the level of their PCB contamination.

Proposed rule changes to 40 CFR 761 "PCB Manufacturing, Processing, Distribution in Commerce and Use Prohibitions" published on 6 Dec 1994 has the potential to significantly impact Naval operations and disposal efforts. Although the proposed rule changes included corrective actions enabling the Navy to continue employing its weapon systems, it included added authorizations, monitoring, disposal, labeling and risk management requirements. Potential actions of concern to the Navy include: 1) continued operation of the systems by either Navy personnel or operation by foreign nationals after a foreign military sales action; 2) eventual dismantling and disposal of the systems, and 3) disposal of entire systems at sea, either as a result of use as targets or as artificial reefs for ecological enhancement. Each of these options may pose a risk to the environment or to human health if the PCBs are released.

The US Navy is actively reducing the number of older vessels, including submarines, which contain PCB materials primarily as additives or contaminants in paint, electrical cable, insulation materials and rubber. The Navy has interests in the remediation of PCB-contaminated sites, disposal of non-remediation materials, authorized use of PCBs, monitoring requirements and PCB record keeping. On-going operations and maintenance activities periodically involve removal, repair and replacement of contaminated materials. The maintenance processes involve removal of the items and yield exposure to bulk materials, airborne debris from chipping, needle-gunning and blasting processes. From a mass balance perspective, the removed material will eventually appear as fugitive emissions or, more likely, as waste streams of contaminated media and solid waste requiring disposal.

PCBs were produced in the United States (principally by Monsanto as Aroclors 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268) for use in closed systems (capacitors and transformers) and open systems such as plasticizers, coatings, inks, and as a fire retardant or an extender in various organic compounds. The Agency for Toxic Substances and Disease Registry (ATSDR) Toxicology Profile contains a review of the chemical and physical characteristics and production and import information (ATSDR, 1993). In 1974, PCB use was restricted to electronic applications in "closed" systems. In the US, production was stopped in 1979. Disposal is limited to chemical waste landfills, incineration and high-efficiency boilers. US Environmental Protection Agency (USEPA)

studies show environmental levels of PCBs have significantly declined since 1980 (ATSDR, 1993).

Scope

The Navy spends an estimated $4 billion annually for vessel maintenance tasks. Should the USEPA-proposed rules be promulgated, the Navy will need to consider its future fiscal planning estimates as added costs will occur. The estimated cost to the Navy for the first year of compliance with the proposed ruling would be $1,150 million; this estimation includes the new sampling and labeling requirements, management of PCB materials for disposal and concrete pad removal at shore facilities with transformers. The annual costs for subsequent years would be approximately $563 million per year, which would include new use conditions and disposal management during maintenance (NCF (NAVSEA Copy Files) #1).

Results reported herein represent a three and one-half month effort to support the Navy in defining an approach for a PCB human health risk assessment and documenting the status of existing data. Through a three phase contractual effort, three objectives were pursued: 1) review of the science and its effectiveness in the current PCB compound specific risk analysis; 2) assess the criteria used in setting the proposed rule changes, and 3) examine means to improve exposure characterization for occupational and environmental scenarios. Additionally, an evaluation and summarization of USEPA Toxic Substances Control Act (TSCA) Docket files of comments on the proposed rule were conducted on relevant correspondence; Naval Sea Systems Command (NAVSEA) files on PCBs were indexed and relevant information on human health risk was summarized.

No empirical or laboratory effort was conducted under this effort; only review of the literature and analysis of existing data were included in the scope. The Navy, under separate but parallel efforts, acquired additional data on potential submarine contamination levels. These data were statistically analyzed and the results are reported here along with further characterization of exposures. Literature on toxicology, human health effects, dose-response assessment and criteria documentation were reviewed and assessed. Results reported from this effort are provided to the Navy for determination if sufficient baseline data are available to perform risk-based decision making on alternatives to PCB article disposal.

This effort consisted of: 1) summary of proposed rule change; 2) concurrent literature search; 3) analysis of the scientific basis for current PCB risk criteria; 4) toxicology summary; 5) environmental and occupational exposure assessment; 6) risk characterization, and 7) recommendations.

SUMMARY OF PROPOSED RULE CHANGE

The USEPA has proposed an amendment to its rules under TSCA for disposal of PCBs per 59 FR 62788, 6 Dec 1994 for revision of 40 CFR 761. The proposed ruling includes:

- New requirements for determining PCB concentration
- Marking, storage, and disposal requirements
- Decontamination levels and procedures
- Reporting and record keeping requirements for PCBs, PCB items, and environmental media contaminated with PCBs or PCBs commingled with radioactive materials
- New references and definitions
- New authorizations and exemptions
- Registration on certain electrical transformers
- Regulation on combustion in industrial furnaces
- Regulation on disposal of liquids in landfills
- Coordination of PCB disposal approval with other Federal and State programs
- Revision of the reportable quantity in the spill cleanup policy
- Coordination of remediation strategies of PCBs with Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response Compensation and Liability Act (CERCLA) provisions.

TSCA Section 6(e)(1)(A) allows the USEPA to promulgate rules prescribing methods of PCB disposal. TSCA Section 6(e)(1)(B) provides the USEPA with the authority to promulgate rules to require marking of PCB items. TSCA Section 6(e)(3)(B) provides that any person may petition USEPA for an exemption from the prohibition on the manufacture, processing and distribution in commerce of PCBs. The USEPA may grant an exemption if an unreasonable risk of injury to health or the environment would not result.

Background

PCB-contaminated would mean anything that contains or contacts PCBs at concentrations of 50 parts per million (ppm) to less than 500 ppm. For surfaces, PCB concentrations greater than 10 micrograms per 100 square centimeters (10 $\mu g/100\ cm^2$) and less than 100 $\mu g/100\ cm^2$ would be defined as PCB-contaminated.

Key sections of proposed rule

Several key sections of the proposed rule that would potentially affect submarine decommissioning (e.g., sale to foreign government, disposal, or ocean sinking) include:

- Authorizations, pre-TSCA uses of PCBs
- PCB non-remediation wastes

- Disposal of PCB/radioactive wastes
- Disposal of PCB-bound materials
- Disposal of small capacitors
- Disposal of solvents
- Transboundary movement of PCBs for disposal
- Oil-filled equipment manufactured after the ban
- Appendix III: "Sampling Non-Liquid, Non-Metal Non Remediation Waste Generated by Processing Materials Containing Recyclable Metals"

Authorizations, pre-TSCA uses of PCBs

Section 761.30(q) would authorize the continued use of PCB articles, at any concentration in use prior to 1979, provided there is monitoring, the material remains intact and does not pose an unreasonable risk. It does not include removal. This section would establish the National Institute for Occupational Safety and Health (NIOSH) recommended exposure level as the occupational exposure permissible exposure criteria and includes an associated surface level contamination criteria. Disposal of PCB articles would need to comply with these requirements; exceptions to these constraints are identified.

PCB non-remediation wastes

These items would include non-liquid bulk waste or debris from human-created structures where construction materials were manufactured or coated (e.g., paint containing PCBs), PCB-impregnated electrical, sound-deadening or other types of insulation and gaskets and all other PCB items or PCBs not otherwise specified in Section 761.60. The USEPA-preferred disposal method as proposed by Section 761.62 is a well-engineered and operated solid waste landfill with appropriate monitoring to detect PCB release to the environment. The proposed rule would allow the applicant to request disposal by incineration, chemical waste landfill or alternative disposal method approved by the Regional Administrator upon application. However, non-uniform concentrations may result in specified limitations per Section 40 CFR 761.62(c)(4). In accordance with 40 CFR 761.62(c), the applicant could make a risk-based disposal request. An alternative to risk-based TSCA disposal approval would be leachability-based disposal per 40 CFR 761.62(b). If the waste, as measured by the Toxicity Characteristic Leaching Procedure (TCLP), is less than 50 micrograms per liter, the waste could be disposed of in a municipal solid waste landfill provided the landfill is notified 15 working days in advance of receipt of the waste. The USEPA sought comments on these self-implementing options of non-remediation wastes under Section 761.62(b). The third proposed disposal option under Section 761.62(a) would allow performance-based disposal in a TSCA-approved incinerator or chemical waste landfill. This option would be viable in cases where the waste had high levels of leachable PCBs or costs were prohibitive for a risk-based disposal approval under the proposed Section 761.62(c).

Disposal of PCB/radioactive wastes

Because of the potential for PCB to be commingled with radioactive waste, this proposed rule would amend 40 CFR 761.65 to allow self-implementation and case-by-case extensions to the one-year time limit for storage and disposal requirements for both PCB and PCB/radioactive wastes. However, the extension would be granted only if there are no unreasonable risks of injury to health or the environment and it can be demonstrated that relevant treatment or disposal actions are being pursued. New PCB/radioactive waste definitions are proposed in Section 761.3. Because of the limited capacity of the Department of Energy (DOE) Oak Ridge incinerator, the USEPA recognizes that PCB/radioactive wastes would require storage beyond the one-year limit. However, periodic extension requests would still be required.

Disposal of PCB-containing materials

The USEPA proposed definition of PCB-containing materials would include the plastic insulating material in electrical cable, or lead cable insulated with PCB oil-soaked paper. The lead cable is used in high voltage distribution of electric power, i.e., 5,000 volts and above. The USEPA welcomed information on any use of electrical cable containing PCBs and potential risks of exposure to workers, the public, and the environment. Cable decontamination procedures would be regulated. "Open burning" of PCB oil-soaked paper in scrap yards would be subject to enforcement action.

Disposal of small capacitors

Proposed TSCA disposal requirements for PCB capacitors are provided at Section 761.60(b)(2). PCBs as a hazardous substance under CERCLA have a reportable quantity of one pound. If fluorescent light ballasts containing PCB small capacitors exceeding one pound are placed in a disposal drum, the situation would generally be regarded as a reportable release under CERCLA. Many facilities are disposing of their light ballasts or small capacitors in TSCA incinerators to simply avoid Superfund liability should the municipal landfill become subject to a CERCLA cleanup action. Twenty-five light ballasts would probably exceed the one pound reporting requirement, as each ballast has about 0.67 ounces of PCBs.

Disposal of solvents

The disposal of solvents exceeding 50 ppm PCBs would need to be in a TSCA approved facility per Section 761.79. The proposed rule would allow disposal of hydrocarbon solvents with less than 50 ppm PCBs, per Section 761.20(e) or decontamination by processes such as filtration.

Transboundary movement of PCBs for disposal

Current regulations in 40 CFR 761.20(b)(2) promulgated under provisions of Section 6(e) of TSCA authorize the import and export for disposal of PCBs only at concentrations less than 50 ppm. It is proposed per Section 761.20(b)(3) to create certain categorical exceptions to the general ban on import for disposal of PCBs at 50 ppm or greater. Sections 761.20(b)(4) and (c)(3) would not allow import or export of PCBs at 50 ppm or greater for purposes other than disposal (including import for use, reuse, or recycling). This restriction could have significant impact on the Navy's ability to sell the submarines to foreign governments. The USEPA would allow import of PCB items for disposal on a case-by-case basis where it would not impose an unreasonable risk of injury of health or the environment. The USEPA considers the use of the PCB items owned by the US government overseas, that are then returned to the US, as neither imports nor exports.

Oil-filled equipment manufactured after the ban

On July 2, 1979, a ban was placed on the manufacture of PCBs in oil-filled equipment. If the equipment is certified to contain no PCBs at the time of manufacture, and has not been subsequently serviced with PCB containing fluids, the equipment would not be assumed to be PCB-contaminated and would not be subject to the provisions of 40 CFR 761.

Appendix III: "Sampling Non-Liquid, Non-Metal Non Remediation Waste Generated by Processing Materials Containing Recyclable Metals"

At least 7.5 cups or 100 gram subsamples would be taken from a uniform pile of waste. They would then be combined into a composite sample for PCB analysis.

ANALYSIS OF CRITERIA USED IN PCB REGULATION

Several regulatory standards and recommended criteria on PCBs are currently in existence. Although these represent the present regulatory levels, most were published some time ago and therefore do not reflect newer studies and interpretations of study results. Several of these standards and criteria are discussed in respect to their bearing on current PCB regulation. The American Conference of Governmental Industrial Hygienists (ACGIH) guideline has been adopted by the Occupational Safety and Health Administration (OSHA) as law. The NIOSH and the International Agency for Research on Cancer (IARC) documents currently stand as official recommendations. The surface contamination standard has been used by USEPA in their regulations and their cancer potency factor is currently used in risk assessments. The proposed rule would elevate the NIOSH recommendation to law, superseding the higher OSHA regulatory levels.

ACGIH Guideline for PCBs

Introduction

The Threshold Limit Values (TLVs), set by the ACGIH were not established explicitly on the potential risk of cancer from exposure to PCBs. The TLV committee recommends a TLV-TWA (Time Weighted Average) of 1 mg/m^3 for mixtures of 42% chlorine and 0.5 mg/m^3 for mixtures of 54% chlorine, with a skin notation for both. These values have been adopted by OSHA as their Permissible Exposure Limits (PELs) and were not changed or evaluated during the 1989 OSHA rule-making on air contaminants.

Basis for guideline

In 1946, the ACGIH began listing PCBs with "toxic dusts, fumes and mists" in its recommendations of maximum allowable concentrations of air contaminants; they recommended an allowable workplace concentration of 1 mg/m^3 for all PCBs. The ACGIH continued to recommend this level until 1956, when they specified 1 mg/m^3 as the TLV for PCB mixtures containing 42% chlorine and 0.5 mg/m^3 for 54% chlorine mixtures (ACGIH, 1956). This recommendation was based upon information in the reports of Schwartz (1936), Drinker (1939), Treon et al. (1956) and Meigs et al. (1954). ACGIH stated that these levels would seem to offer reasonably good protection against systemic toxicity, but may not guarantee complete freedom from chloracne.

In 1961, the ACGIH added the "skin" notation to the TLVs of those substances, including PCBs, which, in liquid form, can penetrate the skin to cause systemic effects (ACGIH, 1961). The skin notation was not intended to include PCBs in solid phase.

ACGIH has repeatedly reviewed the scientific literature and continues to recommend these levels as an adequate exposure value against significant adverse

health effects including cancer. The issue of PCBs actually causing cancer in humans remains under current review. The existing data suggest that any role PCBs have in the development of cancer is highly complex. PCBs appear to have little or no genotoxic effects. It is the more highly chlorinated PCBs, i.e., penta- or hexachlorobenzenes, that have the greater carcinogenic potency in rodents; however, toxicity appears to decrease with mixtures exceeding 60% chlorine (Safe, 1994). Hence, the TLV is lower for 54% mixtures than the TLV is for 42% mixtures; no TLVs are specified for 60% or 68% mixtures. There is also inadequate epidemiological evidence for the carcinogenicity of PCBs in regulated occupational settings (ACGIH, 1991).

NIOSH Recommendation for PCBs

Introduction

The criteria for the NIOSH Recommended Exposure Limit (REL) (1 $\mu g/m^3$), established in 1977, is primarily based on documented cases of chloracne, liver toxicity (Meigs et al., 1954; Hasegawa et al., 1972; Hara et al., 1974, 1975; Ouw et al., 1976; Levy et al., 1977), irritation of skin and mucous membranes (Ouw et al., 1976; Levy et al., 1977), and adverse reproductive effects (Linder et al., 1974; Allen et al., 1974; Barsotti et al., 1976). The studies do not demonstrate that PCBs alone can cause these effects; which increases the conservatism of the initial 1977 NIOSH recommendation. The following paragraphs describe the findings upon which NIOSH based its REL.

Basis for recommended standard

Most of the chloracne cases identified involved work with or around heated PCBs (Birmingham, 1964; Hasegawa et al., 1972; Oliver, 1969; Ouw et al., 1976). In one study at a capacitor manufacturing plant where chloracne was common, PCB vapors were detected at 0.095-0.95 mg/m^3 and particulate PCB concentrations were found within the range of 0.02-0.65 mg/m^3 (Hasegawa et al., 1972). One major problem with the association of chloracne with PCBs at levels as low as 0.095 mg/m^3 is the possibility that other contaminants in the mixtures may be responsible for the adverse effects. In the case of heated PCBs, polychlorinated dibenzofurans (PCDFs) and possibly polychlorinated dibenzodioxins (PCDDs), which are highly toxic combustion products of PCBs, would likely be present. PCDFs have reportedly been released from heated PCBs at temperatures as low as 300°F, while PCDDs are produced at higher temperatures (approximately 700°F) (Buser, 1979). All PCB mixtures contain some contamination from the manufacturing process. Therefore, it is questionable whether the cause of chloracne was actually PCBs, furans, dioxins, other contaminants or a combination of the above.

In the majority of studies where chloracne was found there were indications of liver injury (Meigs et al., 1954; Hasegawa et al., 1972; Hara et al., 1974, 1975; Ouw et al., 1976). In these studies, liver injury occurred with exposures at the lowest levels of all the

occupational exposure ranges reported. Again, it should be noted that these studies involved heated PCBs; exposure concentrations of PCB congeners or contaminants such as PCDDs were not identified. Also most of these studies did not identify whether the PCB concentrations represented vapor or particulate phases or the proportions of both when exposure to a combination of particulates and vapor was involved.

Adverse developmental effects, such as low birth weight and chloracne, were noted among human and animal infants nursed by mothers with high PCB exposures (Curley et al.,1973; Yoshimura, 1974; Bell, 1976). It has since been demonstrated that the adverse effects noted in these studies were likely due to PCDD/PCDF contaminants in the PCB mixtures (Kunita et al., 1984; Masuda et al, 1985; Safe, 1994).

NIOSH concluded that PCBs were potential carcinogens and that occupational and animal studies have not demonstrated a level of exposure that will not subject the worker to possible liver injury. Hence, it was recommended that the TWA concentrations of PCBs in the breathing zone of workers be maintained at or below the minimally detectable TWA concentration for up to 10-hour workday, 40-hour workweek. The minimally detectable concentration of PCBs for the monitoring of occupational exposures at that time was considered to be 1.0 $\mu g/m^3$ (NIOSH, 1977).

IARC Recommended Criteria

Introduction

The IARC regards all PCBs as being probable human carcinogens (IARC Group 2A). This determination is based on "limited human and insufficient animal" carcinogenicity data. Although several studies associate an increased risk of hepatobiliary cancer with PCB exposure, the human data is considered limited because study numbers were small, dose-response relationships could not be proved and confounding factors could not be excluded (IARC, 1987). The animal carcinogenicity data is questionable since malignant tumors were not produced in more than a single species during several separate studies; dose-response relationships were also not observed (IARC, 1978). The studies that IARC (1978; 1987) found to be pertinent are discussed below; the references remain as originally cited.

Basis for recommended criteria

Occupational exposures: Workers heavily exposed to Aroclor 1254 were diagnosed with a significant increase (2/31) in malignant melanomas; cancers at other sites were also reported. Exposure to other chemicals was probable (Bahn et al., 1976; 1977). Of 2,500 US workers exposed to PCBs as identified in the 1981 Brown and Jones study and the 1987 Brown study, a significant number (five) of liver and biliary cancer deaths were observed. Four of the five deaths were women. Male workers at a capacitor

plant in Italy who were first exposed to 54% chlorine and, later, 42% chlorine PCBs were diagnosed with a significant excess of all cancers; the predominant forms were digestive, lymphatic and hematopoietic cancers. Female workers showed a slight increase in cancer of the lymphatic and hematopoietic tissues (Bertazzi et al., 1982). Subsequently the study was expanded to 2,100 people who worked during 1946-1982. The workers, male and female, had significantly increased rates of cancer mortality as compared to local populations. In males, total gastrointestinal cancers were increased; deaths from hematological neoplasms were increased among females (Bertazzi et al., 1987). A Swedish study examined 142 male capacitor plant workers exposed to PCB mixtures containing up to 42% chlorine between the years of 1965 and 1978. There were no significant increases in cancer deaths or incidence as compared to the local population. One highly exposed worker developed two relatively rare tumors (a malignant lymphoma and a slow-growing desmoid mesenchymal tumor) ten years after the start of exposure (Gustavsson et al., 1986).

Accidental ingestion exposures: In 1984, Umeda reported on the Yusho incident in Japan involving a large population which had ingested cooking oil contaminated with PCBs. During the period from 1963 through 1983, Yusho patients showed a significantly increased risk of all cancers; the risk of primary liver cancer was increased nearly five times. Co-contamination of the cooking oil with polychlorinated quaterphenyls and PCDFs was confirmed. A dose-response relationship could not be formed. A later study of 887 male Yusho patients confirmed a significant increase in mortality due to total malignancies (33), liver cancer (9), and lung cancer (8) as compared to the local population. Confounding exposures, namely PCDFs or PCDDs, could not be ruled out. There were no significant increases in cancer mortality for the 874 female Yusho patients also examined (Kuratsune et al., 1986). Kikuchi (1984) performed autopsies of ten Yusho patients; the two adenocarcinomas of the liver that were found could not be directly associated with PCB exposure. In 1983 and 1984, 79 and 125 Yusho patients were examined with ultrasonic and tumor marker tests; no hepatic-cell carcinomas were found (Okumura and Sakaguchi, 1985). Unger et al. (1982) associated PCB levels in subcutaneous adipose tissue with cancers of the pancreas, stomach, colon, prostate and ovaries. In 1984, Unger et al. were unable to associate PCB content in breast adipose tissue with breast cancer.

Animal carcinogenicity studies: Male mice fed 500 mg Kanechlor 500/kg of diet developed liver nodules after 32 weeks. Mice receiving 0, 100 or 250 mg/kg Kanechlor 500 or 0, 100, 250 or 500 mg/kg Kanechlor 300 or 400 did not develop tumors of any type (Ito et al., 1973). Male mice receiving 300 mg Aroclor 1254/kg of diet for 6 or 11 months developed hepatomas; the results showed a dose-response relationship. Adenofibrosis liver lesions were seen in all mice fed Aroclor 1254 for 11 months (Kimbrough and Linder, 1974). Male and female rats fed 0, 20, 100, 500 or 1000 mg Aroclor 1260/kg diet responded significantly with hepatic adenofibrosis in a dose-response fashion. A higher response rate occurred in rats fed 0, 20, 100 or 500 mg Aroclor 1254/kg of diet (Kimbrough et al., 1972). Female rats fed 38.5 to 616 mg Kanechlor 400/kg of diet developed significant adenomatous nodules in the liver after 400 days; treated male rats did not produce lesions (Kimura and Baba, 1973). Ito et al. (1974) reported effects of

dosing male rats with Kanechlor 300, 400, or 500 at 0, 100, 500, or 1000 mg/kg of diet. Cholangiofibrosis occurred at the 1000 mg dose level; nodular hyperplasia of the liver occurred at all dose levels except control. All effects increased with degree of chlorination and dose. Kimbrough et al. (1975) reported significant hepatocellular carcinomas and neoplastic liver nodules in female rats exposed to 100 mg Aroclor 1260/kg of diet for 21 to 22 months. PCB intake declined from 11.6 mg/kg body weight-day to 6.1 mg/kg at 3 months of exposure and to 4.3 mg/kg at 20 months of exposure. There were no significant increases of non-hepatic tumors. Norback and Weltman (1985) and Schaeffer et al. (1984) also observed benign and malignant hepatic neoplasms in rats. Rats dosed orally with Aroclor 1254 responded with significant intestinal metaplasia as well as hepatocellular carcinomas and adenomas (Ward, 1985). Induction of skin tumors in mice was inconclusive due to inadequate testing (DiGiovanni et al., 1977; Hori et al., 1985).

USEPA Surface Contamination Standards

Introduction

Surface contamination standards appear to have evolved from USEPA in the recent past. Two internal memoranda are the only formal references identified which describe the process employed to derive the standards. Hammerstrom (1986) provided guidance on an acceptable level of quantification for PCB transfer from surfaces to skin. Schweer (1986) expanded that methodology to cover dermal exposures to high contact surfaces in residential settings.

Basis for recommended standard

Risks from surface contamination are based upon an estimation of absorbed systemic dose from a dermal transfer mechanism. Little impact on the lifetime average daily dose is estimated from volatilization, inhalation or ingestion from contaminated surfaces (Hammerstrom, 1986). A potency factor of 4 $(mg/kg\text{-}day)^{-1}$, transfer/absorption rate of unity (100%), lifetime exposure of 70 years (25,550 days), contact with 140,000 cm^2 of contaminated surface (10 μg/ 100 cm^2), and lifetime average daily dose calculated for 50 kg body weight was used to derive a risk of 4.4×10^{-5} (Schweer, 1986). Hammerstrom (1986) used low and high contact to 10 $\mu g/100\ cm^2$ surfaces at a risk of 10^{-6} to back calculate transfer rates resulting in a range from 3.1% to 28%.

The occupational risk assessment analyses for both low contact areas and high contact areas were examined. Lifetime exposure areas of 41,200 cm^2 for low exposure and 11,600 cm^2 for high exposure areas and transfer rates of 1% and 25%, respectively, yielded a risk of 10^{-6} at the 10 $\mu g/100\ cm^2$ contamination level (Hammerstrom, 1986).

The method employed by the USEPA to estimate the risks from surface contamination conformed to the policy of the agency in the mid-1980s. It accepted the worst-case scenario, assumed total absorption, estimated high material transfer rates and accepted the potency factor in use at the time within the agency. Potential weaknesses in the scenario include: surface area contacted; duration of exposure; assumption of total absorption; and lack of quantified estimates of transfer rates.

USEPA PCB Cancer Potency Factor

Introduction

In 1986, the USEPA prepared an assessment of the adverse health effects associated with PCBs. The USEPA's intent were to suggest acceptable exposure levels whenever sufficient data was available (USEPA, 1986a). In September 1996 the USEPA released PCBs: Cancer Dose-Response Assessment and Application to Environmental Mixtures, EPA/600/P-96/001F. This report updates PCB cancer dose-response toxicity information.

Basis for potency factor

The new assessment differentiates between mixtures and considers cancer studies to develop a range of dose-response slopes. This allows for the selection of an appropriate slope representative of the mixture and exposure pathway. Upper-bound potency estimates for PCB mixtures and a range of central estimates, as well as sources of uncertainty are included.

Implications for dismantling/disposal or continued use of Naval submarines

The proposed PCB ruling would allow the continued use of PCB containing materials which exhibit an environmental release rate below 0.001 mg/m^3 (1.0 $\mu g/m^3$) for a 10-hour workday, 40-hour workweek, as measured by workplace air monitoring. Alternatively, a surface contamination level of less than 10 $\mu g/100\ cm^2$ would be allowed. Quarterly workplace air monitoring activities would be required for the first year and annually thereafter. No criteria for this guidance is given in the ruling; however, it appears that the allowable airborne level was adopted from the NIOSH REL established in 1977.

By adopting the NIOSH recommendation, the PCB ruling would, in fact, set a more stringent standard for allowable occupational exposures to PCBs than the OSHA standard. OSHA's PELs are 1.0 mg/m^3 for Aroclor 1248 and 0.5 mg/m^3 for Aroclor 1254 mixtures.

In US Navy exposures, it is expected that PCB-containing particulates will become airborne from the PCB removal activities, but PCBs in the vapor phase will not be released. One possible exception is the metal cutting processes utilizing flame torches. Vapor releases have largely been prevented by cleaning the PCB contamination from the cutlines prior to metal cutting.

In comparison to PELS for PCBs in other industrialized nations with occupational and environmental standards similar to those of the US, the allowable airborne level in the proposed rule is much more stringent. For example, Australian PEL is 0.5 mg/m^3 and the 15-minute Short Term Exposure Limit (STEL) is 1 mg/m^3; where PCBs are also categorized as probable human carcinogens, with a skin notation. Germany enforces a 0.5 mg/m^3 PEL, with a 30 minute STEL of 5 mg/m^3. Sweden's permissible PCB limit is 0.01 mg/m^3; the 15 minute STEL is 0.01 mg/m^3 (ACGIH, 1991).

The proposed rule would offer the Navy an authorization for continued use of the PCB-contaminated materials but would include significant monitoring, labeling and disposal constraints.

TOXICITY

Available Epidemiological Data

Overall, studies of PCB carcinogenicity have been inconsistent and provided limited evidence (IARC, 1987). Numerous epidemiological studies of workers exposed to PCBs have been conducted in the US (Brown and Jones, 1981; Brown, 1986; Shalat et al., 1989; Sinks et al., 1992), in Sweden (Gustavson et al., 1986), in Italy (Bertazzi et al., 1987) and in Canada (Yassi et al., 1994). However, none of these studies have provided conclusive evidence that PCB exposure is causally related to human cancers. Although excess risks of hepatic, biliary tract, or gall bladder cancer and of digestive and pancreatic cancers have occurred, many were not statistically significant when analyzed against expected cancer occurrences. Often, workers were found to be simultaneously exposed to other chemicals including trichloroethylene, toluene, and methyl isobutyl ketone. Additional reasons for inconclusive study results include small study numbers, combination of data from multiple plants in different geographical regions, high blood levels of PCBs in workers from areas of lower cancer incidence and questionable grouping of liver, biliary and gall bladder cancers. Due to these limitations, including concurrent exposure to other chemicals, PCB exposures could not be causally related to hepatic cancer incidence.

Similarly, statistically significant increases in malignant melanoma, pancreatic cancer and ocular melanoma incidence were reported (Bahn et al., 1976, 1977: Lawrence, 1977; NIOSH, 1977; Davidorf and Knupp, 1979; Emmett et al., 1988). These studies reported Aroclor 1254, 1242 and 1016 in frequent use over extensive periods of time. However, these studies were generally regarded as inconclusive since PCB exposures were not quantified, the number of cases and the cohort sizes were frequently small, and expected cancer rates were based on US population data rather than on local rates. Additionally, the workers were simultaneously exposed to various solvents (toluene, xylene, methyl ethyl ketone, trichloroethylene, and 1,1,1,-trichloroethane) and unspecified metals from brazing and soldering operations.

Yusho (1968) and Yu-Cheng (1979) ingestion incidents

The most convincing evidence for any lack of human toxicity is found in the data from two incidents of human PCB ingestion in contaminated rice oil. There is no conclusive evidence of cancer in people who ingested heated rice oil containing PCBs during the Japanese Yusho and Chinese Yu-Cheng incidents (Hsu et al., 1985; Kuratsune et al., 1986). Although several symptoms were reported, these disappeared over time. Subsequent monkey studies using PCBs with and without PCDFs provided evidence to suggest the PCDFs were the contaminants that caused the Yusho and Yu-Cheng symptoms.

Conclusion of human epidemiology data

Based upon the extensive epidemiological studies and human experience of PCB exposures, some PCB congeners have been characterized as probably carcinogenic (IARC, 1987).

Review of Experimental Dose Response Studies

There are no studies regarding cancer in animals after inhalation exposure to PCBs. Six PCB feeding studies have been conducted. Two of these studies (Kimbrough et al., 1975; Norback and Weltman, 1985) reported statistically significant occurrence of malignant responses (adenocarcinoma, hepatocellular carcinoma and neoplastic nodules) to Aroclor 1260 in rodent species.

Rats

A recent rat study (Brunner et al., 1996) tested both sexes of Sprague-Dawley rats at several dose levels for Aroclors 1260 (25, 50, or 100 ppm), 1254 (25, 50, or 100 ppm), 1242 (50 or 100 ppm), and 1016 (50, 100, or 200 ppm) for a duration of 104 weeks. This effort provided the most comprehensive data for dose-response modeling and demonstrated a statistically significant increased incidence of liver adenomas or carcinomas in female rats for all Aroclors and in males for 1260. Several of these tumors were hepatocholangiomas. Thyroid gland follicular cell adenomas or carcinomas were increased in males for all Aroclors with a significant dose trend noted for Aroclors 1254 and 1242.

Kimbrough et al. (1972) conducted a study on Aroclor 1254 and 1260. Neither neoplastic nodules nor hepatocellular carcinomas developed in Sherman rats (10 per sex) treated with dietary doses as high as 72.4 mg/kg-day for eight months. Increased incidence of adenofibrosis of the liver was observed; adenofibromas are not carcinomas and were not considered pre-cancerous by the investigators. However, sensitivity of this study was limited by the small number of animals and the short duration. Due to these limitations, carcinogenicity can neither be concluded or discounted.

Kimbrough et al.(1975) reported 14% (26/184) hepatocellular carcinomas and 92% (170/184) hepatic neoplastic nodules in female Sherman rats fed an estimated dose of 5 mg/kg-day Aroclor 1260 for approximately 21 months. This was considered a significant increase in both hepatocellular carcinomas and neoplastic nodules. Incidence of neoplastic lesions was not increased in tissues other than liver; all major tissues and organs were examined. Subsequently, Norback and Weltman (1985) reported late appearing, non-metastasizing liver tumors in Sprague-Dawley rats fed an estimated average dose of 3.45 mg/kg-day Aroclor 1260 for 24 months. Hepatocellular carcinomas or neoplastic nodules were found in 95.7% (45/47) of female rats and 15.2% (7/46) of male rats treated 18 months or longer.

In a study conducted by the National Cancer Institute (NCI) (1978), male and female Fisher 344 rats were fed Aroclor 1254 in estimated doses of 1.25, 2.5, or 5.0 mg/kg-day for 104 or 105 weeks. Low incidences (4.2% [1/24]) of hepatocellular carcinomas and unspecified adenomas (12.5% [3/24]) occurred in the mid-and high-dose groups, but not in the control or low-dose groups. A non-significant occurrence of lymphoma and leukemia was also reported. Analysis of these results revealed no statistically significant difference between treated groups and matched controls.

Re-examination and reclassification of the 1978 NCI liver data by Ward (1985) found that total tumor incidence (hepatocellular adenomas and carcinomas) was significantly increased ($p<0.05$) in the high-dose males. Morgan et al. (1981) also re-examined the NCI (1978) gastrointestinal data and found increased incidence of stomach adenocarcinoma and metaplasia that was dose-related in six treated rats. The investigators commented that the stomach adenocarcinoma and intestinal metaplasia appeared to be related and might have the same initiating mechanism. They concluded that Aroclor 1254 led to induction of intestinal metaplasia and probably to induction of adenocarcinoma in the glandular stomachs of Fisher 344 rats. No correlation between stomach and liver lesions was found. Ward (1985), in re-examination of the NCI (1978) gastrointestinal data, noted that the metaplastic lesions were similar to those seen in monkeys, but differed in being focal and singular while monkey lesions were diffuse.

Schaeffer et al. (1984) reported 50% (63/126) occurrence of neoplastic liver nodules and 48% (61/126) occurrence of hepatocellular carcinomas in male Wistar rats fed 5 mg/kg-day Clophen A-60 for up to 832 days. The incidences of these lesions were significantly ($p<0.05$) higher than control values of 3.8% (5/131) and 0.8% (1/131), respectively. The authors observed a time-dependent progression from altered foci to neoplastic nodules to hepatocellular carcinoma. The Clophen A-60 mixture was reported to be free of PCDFs, but it is not certain whether these contaminants, including PCDD's, were actually absent from the mixture. Detection limits, analytical techniques, and treatment method of the mixture to remove PCDFs were omitted.

Also Schaeffer, et al. (1984) evaluated the carcinogenicity of lower chlorinated PCB mixtures. Male Wistar rats fed Clophen A-30 at 5 mg/kg-day for up to 832 days developed neoplastic liver nodules (29% [38/130]) and hepatocellular carcinomas (3.1% [4/130]) compared to control occurrence of 4 % (2/53) and 2% (1/53), respectively. The increased incidence of neoplastic nodules was statistically significant ($p<0.05$), but this pathology classification could have included non-neoplastic hyperplasia as well as benign adenomas. Combined incidence of neoplastic nodules and hepatocellular carcinomas was 7.7% (10/130) and 4.5% (6/131) in the treated and control groups, respectively. The investigators concluded "Clophen A 60 had a definite, and Clophen A 30 a weak, carcinogenic effect on rat liver."

Mice

Ito et al. (1973) found 58.3% (7/12) liver nodular hyperplasia and 41.7% (5/12) hepatocellular carcinomas in mice fed 65 mg/kg-day Kanechlor 500 (52-54% chlorine by weight) for 32 weeks. Neither response was determined significant. The statistical power of this study was low due to the small number of animals, relatively short treatment duration and no post-treatment observation period. These lesions were not observed in mice treated with lower doses (32.5 or 13 mg/kg-day) of Kanechlor 500. Other tissues (non-liver) were not examined histologically by Kimbrough and Linder (1974) nor by Ito et al. (1973).

No proliferative lesions (nodular hyperplasia or hepatocellular carcinoma) were observed in mice fed estimated doses of 65 mg/kg-day, or less, Kanechlor 400 (48% chlorine by weight) or Kanechlor 300 (40-42% chlorine by weight) for 32 weeks (Ito et al., 1973). Limitations of this study included small numbers of animals, a relatively short treatment period, and no observation period following treatment.

Kimbrough and Linder (1974) conducted another study and found significant increases (45.5% [10/22]) in benign hepatomas among male Balb/c1 mice fed an estimated dose of 49.8 mg/kg-day Aroclor 1254 for 11 months. Increases were not significant (4.2% [1/24]) in mice similarly treated for six months followed by a five-month recovery period. Hepatomas were non-existent in the two control groups. No malignant tumors were observed, but investigators noted that the tested mouse strain only rarely develops spontaneous hepatomas. Therefore, the hepatomas were considered potentially malignant. Additionally, adenofibrosis occurred in all 22 mice treated in the 11-month exposure group.

Assessment and conclusion of dose response data

Neither mouse study contained confirming evidence of any hepatocarcinoma. The above studies showed that potency of PCB mixtures increases with chlorine up to 60%.

The regulatory community used numerous studies including: Brunner et al. (1996), Norback and Weltman (1985) and Kimbrough et al. (1975) to develop a range of human potency and slope estimates.

USEPA's Carcinogenicity/Potency Designation, as of September 1996

In 1987, the Safe Drinking Water Criteria Document for PCBs cited a slope factor of 7.7 $(mg/kg/day)^{-1}$ based on the total incidence of liver carcinomas and neoplastic nodules reported by Kimbrough et al. (1975) and Norback and Weltman (1985). The newly released PCBs: Cancer Dose-Response Assessment and Application to Environmental Mixtures provides slope estimates and three tiers of human potency for environmental mixtures. The high risk and persistence tier is used for pathways that tend

to increase risk, such as Aroclor 1260 and 1254. Criteria include dermal exposure (if an absorption factor has been applied), food chain, sediment or soil ingestion, dust or aerosol inhalation, presence of dioxin-like congeners, or early-life exposures. The central slope (Per mg/kg-d computed as 0.10/ED10) is 1 and upper-bound slope (Per mg/kg-d computed as 0.10/LED10) is 2. The low risk and persistence tier has a central slope of 0.3 and upper-bound slope of 0.4 and is used for dermal exposure (if no absorption factor has been applied to reduce external dose), inhalation of evaporated congeners, and ingestion of water-soluble congeners. The lowest risk and persistence tier has a central slope of 0.04 and upper-bound slope of 0.07 and used for mixtures with congeners containing 4 chlorines comprising less that 1/2% of total PCBs.

In 1991, the Institute for Evaluating Health Risks (IEHR) recognized the need for consensus criteria for diagnoses of liver tumors and neoplasms in rats (Moore, 1991; Moore et al., 1994). The IEHR group of seven expert toxicologists and veterinarian pathologists undertook a re-evaluation of the animal data on PCBs. The studies which dealt with rats exposed to 60%, 54% or 42% chlorine content PCBs were considered to be the best available on which to evaluate cancer potential. The study tissues were blind code marked and examined by the panel of experts without knowledge of the prior diagnoses. The studies on Aroclor 1260 consistently resulted in a high incidence of liver tumors. Studies of the lower chlorine content mixtures showed no statistically significant increases in liver tumors. They concluded that "the science policy of assuming that all PCBs are probable human carcinogens with a potency equivalent to the mixture that contains 60% chlorine has no scientific foundation and should be reconsidered" (Moore et al., 1994). They also indicated that it is not proper to continue a policy which does not consider newer data (i.e., developed subsequent to initial judgments) that indicate such formulations are non carcinogenic or weakly carcinogenic. Furthermore, only 12% of all PCBs sold in this country had the 60% chlorine formulation. IEHR recommended development of separate risk assessments for each major PCB group or formulation. IEHR concluded the current cancer policy clearly overestimates cancer risks associated with PCB exposures. Additionally, "there appears to be no scientific basis for continuing the practice of selecting only part of the available data for deriving potency estimates." The IEHR level would reduce any cancer risk estimates by a factor of four. IEHR recommended using 1.9 $(mg/kg\text{-}day)^{-1}$ instead of the previous USEPA value of 7.7 $(mg/kg\text{-}day)^{-1}$ (Moore et al., 1994).

PCB Health Effects Summary Conclusion

A review of carcinogenicity criteria and the experimental database of PCB health effects indicates there are insufficient scientific data to designate all PCBs as carcinogenic. The 1996 USEPA tiered approach to PCB environmental mixtures provides ranges with estimation of dose associated with 10% increased incidence and 95% lower bound on ED10. Further information on contaminant interactions, specific congener toxicity, dose/response and pharmacokinetics are necessary to appropriately interpret PCB toxicity.

ENVIRONMENTAL AND OCCUPATIONAL EXPOSURE ASSESSMENT

Scenarios

Exposure information was collected from two sources. Literature references on case studies and reports on environmental contamination levels were assessed to establish baseline information. Secondly, samples collected both during and prior to this effort were statistically assessed to characterize human exposures. Reference to additional information has been acquired, but analysis was not included in the current effort as access to those data has not yet been authorized.

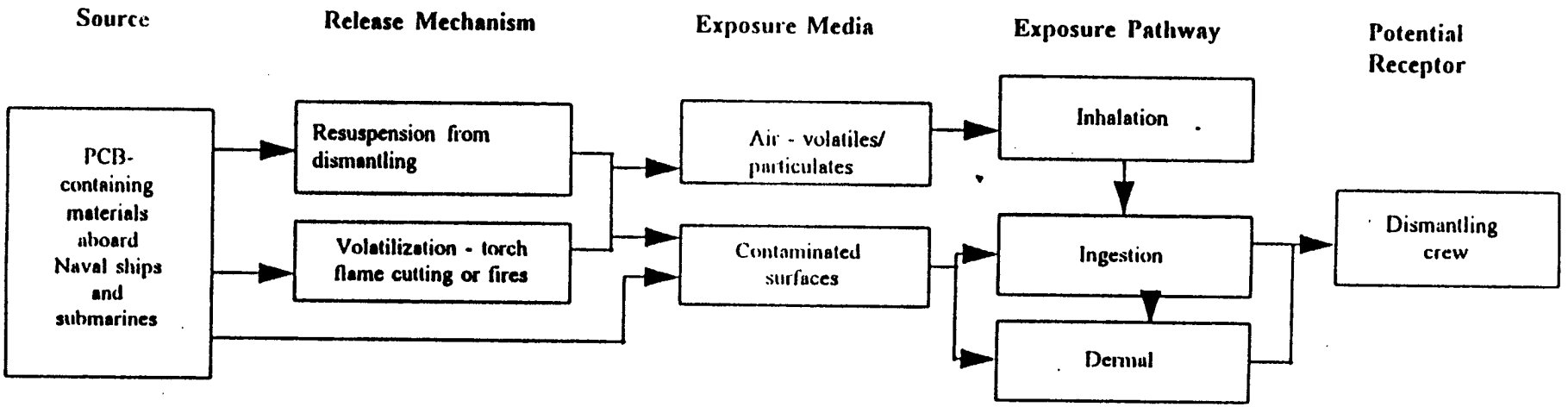
Sources of potential PCB items found on nuclear submarines are (Puget Sound Naval Shipyard (PSNS), 1994):

- Ensolite hull insulation (MIL-P-15280)
- Cork hull insulation (MIL-C-561/HH-C-561)
- Armaflex hull insulation (MIL-P-15280)
- Pipe, vent, or machinery insulation, lagging cloth and adhesives
- Heat resistant and aluminum paste paint (TT-P-28, MIL-P-14276 or DOD-P-24555)
- Banding and sheet rubber used for cableways, pipe hanger liners, sound isolation mounts, vent gaskets
- Wool felt ventilation gaskets (MIL-G-20241/MIL-STD-2148)
- Electrical cable
- Felt leached areas in bilges
- Other materials used as damping installed over previously installed damping wool felt
- Gas pads and rubber products found in missile tube liners (mastic may have asbestos)

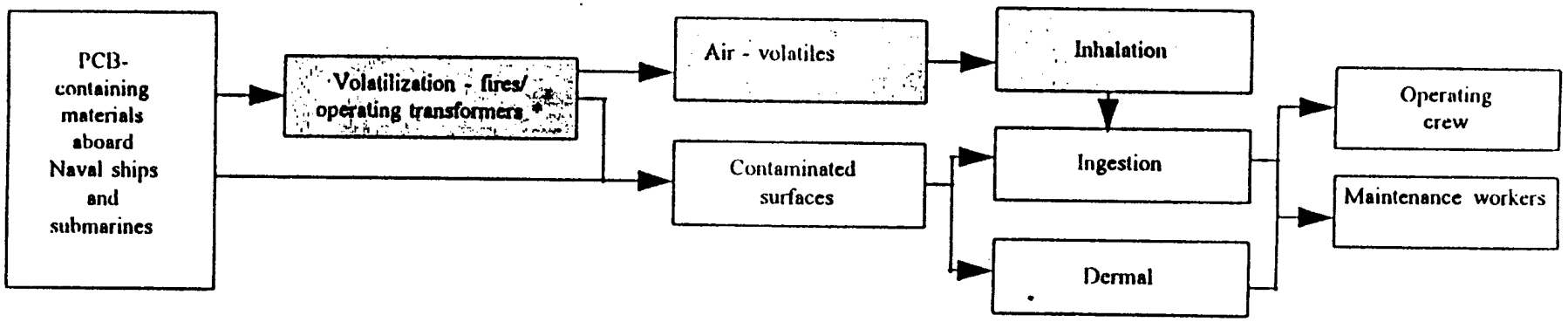
Note: A specific evaluation is prescribed for submarine reactor compartment disposal per Reactor Compartment Disposal Manual NAVSHIPDPUGETINST P9210.15A. Radioactive material commingled with PCB waste must meet both the 40 CFR 761 requirements in addition to any radioactive requirements specified.

With respect to human health risk assessments, there is a limited set of scenarios which requires analysis. If the Navy continues to employ the PCB containing submarines/surface ships as operational weapons platforms or seeks approval for foreign military sales, the resultant exposure scenario is operational. If dismantling of the vessels is selected, the scenario includes both dismantling activities and the ultimate disposition of contaminated articles. A conceptual model of the exposure scenarios is provided in Figure 1.

Scrapping Scenario



Operating Scenario



NOTES:

= insignificant or incomplete pathway

* Data does not indicate the presence of a vapor phase

Figure 1. RISK ASSESSMENT CONCEPTUAL MODEL

Operations and maintenance scenario

A health risk assessment on the operations scenario would consider the contamination levels, spatial distribution of contaminated articles, processes employed, and the modes of exposure. In effect, this scenario would involve normal crew operation, routine maintenance at sea and refurbishment/repair in port. Due to gaps in the regulatory language, a strict interpretation of existing rules suggests there is no current authorization to use PCB contaminated weapons systems where the contamination is not "totally enclosed" in electronic components. The data provided in the following section indicate that PCB-containing articles are widespread throughout the submarines and surface ships.

Operational crews vary significantly from the average population. They exclude both ends of the age distribution in that both the very young and old are not present; ages range from approximately 17 to 50 years. The vast majority of the Navy population is male; however, women also serve aboard surface vessels. Naval personnel with a weakened health status are generally not included, at least from a chronic exposure scenario perspective, due to military medical standards. The population does include all racial groups.

Potential exposure pathways include dermal, inhalation and ingestion. Dermal exposure can occur through contact with low and high exposure surface areas; casual contact may occur with contaminated articles as part of mission execution or as part of maintenance operations as described below. Inhalation pathways are feasible through volatilization of PCB liquids and generation of PCB contaminated dusts or PCB aerosols; however the air monitoring data gathered on a number of operating activities indicate that inhalation is an insignificant pathway. Ingestion is feasible through transfer of PCBs from contaminated skin directly to the mouth, from contaminated surfaces to food stuffs and/or from ingestion of PCB dusts trapped in the bronchial mucous, refluxed and swallowed.

Further analysis of the repair and refurbishment activities is required. During these two complex activities, individuals could be exposed to the contaminated articles normally located in low probability contact areas (e.g., insulation, gaskets, etc.). The frequency, duration, transfer factors and absorption rates of PCBs in this activity were estimated for the risk characterization.

Scrapping scenario

In this scenario, the submarines/ships would be brought into port, decommissioned, dismantled, decontaminated and disposed of as scrap. The exposure factors identified during the refurbishment would be very similar to this scenario with some notable exceptions. This activity would be conducted in port but likely not in the same facility as the refurbishment. Much less care could be expected in execution of the tasks since the outcome is scrapping of the materials. The removal processes would be

conducted onboard the submarine. During the process, the ventilation system would become inoperable.

Significant worker personal protection would be employed during these activities. The level of Personal Protective Equipment (PPE) necessary depends upon the extent of the exposure expected. If exposure to soot is expected, workers should wear outer coveralls made of a non-woven fabric such as spunbonded Tyvek to exclude particulates. If the exposure is to liquids (as could be the case if a transformer spill occurred) or if the form of contamination is unknown, the outer coverall should be made of chemically resistant materials such as Saranax-coated Tyvek or Viton-coated neoprene. Gloves and boots should be made of neoprene, nitrile, butyl rubber, or Viton; these materials have been shown to be resistant to permeation by PCBs (Schwoppe et al., 1985). Hence, dermal contact during some dismantling operations may be an incomplete exposure pathway, not requiring assessment.

Receptors would consist of industrial workers and laborers, both male and female. Since dismantling would include torch cutting of structures, volatilization of PCB coatings and other materials could occur. In addition, thermal byproducts such as PCDFs may result from hot work on PCBs. Therefore, inhalation could also be a potential exposure pathway for some activities. No contamination of food or drinking water should be expected because eating and drinking are allowed only in "clean" areas.

Characterization of PCB Contamination on Navy Vessels

The following subsections present PCB characterization information from Naval vessels; the information was obtained from three sources: the NAVSEA Copy Files (NCF), PSNS, and the Bremerton Hospital. The NCFs provided useful PCB survey data taken from surface ships and submarines. That information included air samples, wipe samples (e.g., electrical cables, surfaces of high contact, paint) and bulk samples.

The Bremerton Navy Hospital data included air monitoring results on a number of submarine dismantling activities. In addition, information pertaining to air monitoring results before and after a transformer fire on the USS Thomas Edison were included.

The submarine media database obtained from PSNS contains PCB data gathered between 1990 and 1995. The database, created for research and development, contains over 22,000 bulk and swipe samples, mainly taken from dismantled pieces.

Airborne emissions

Ventilation system monitoring: In 1990, the Navy conducted air monitoring in submarine and surface ship ventilation systems to determine whether airborne PCBs are escaping from ventilation systems. A total of 66 samples were collected from both

submarines and surface vessels using NIOSH Method 5503 at intake vents "upstream" and outlet vents "downstream" of PCB contaminated gaskets. Gasket materials were tested and were confirmed to be PCB contaminated. Volumes of air samples ranged from 338 to 438 liters, and no detectable PCBs were found in any of the samples during normal operating conditions. This information strongly suggests that PCBs are not airborne contaminants in submarine or surface ship spaces and are not emitted from the ventilation systems equipped with PCB felt gaskets (NCF #24).

Although PCBs are not an airborne contaminant during normal operating conditions, the Navy was concerned that PCBs could become airborne during the cleaning of ventilation ducts. Shipboard ventilation system ducts are periodically cleaned using an extraction system which employs a flailing device to loosen dirt and dust and a vacuum unit to collect the resultant airborne debris. Some abrading of the exposed edges of the PCB-laden gasket sometimes occurs. To determine if this duct cleaning system causes the release of PCBs into the atmosphere, the Navy collected air samples from USS Nimitz (CVN 68) using NIOSH Method 5503 in two locations: 1) air exhausted by the vacuum and 2) air outside the duct approximately 18" away from the duct opening. The samples were collected under three conditions: 1) with vacuum running, prior to cleaning with the flailing device, 2) during operation of both the vacuum and flailing device, and 3) after removal of the flailing device with the vacuum still running. The laboratory analyses indicated there were no detectable airborne PCBs discharged from the extraction unit (NCF #24). Again, this information concludes that PCBs are not an airborne contaminant on submarines and surface ships, even during ventilation maintenance.

Bulk samples taken from the material collected in the vacuum tank of the ventilation extraction system indicated 3600 ppm PCB in the debris loosened by the mechanical abrasion of felt. As a result, the Navy now requires personnel operating the extraction unit to wear proper PPE and to treat the collected dust and debris as PCB waste. The PPE and handling procedures eliminate the need for personnel contact with vent joint gaskets (NCF #24).

At sea monitoring: On 16 Sept 1989, air sampling was conducted on the USS Guardfish (SSN 612) while underway. PCBs were not detected by laboratory analysis. The air samples were collected (using NIOSH Method 5503) in the maneuvering room, engine room upper level (above the main engine complex), and engine room lower level (main engine complex) (NCF #1).

Monitoring of dismantling activities: Industrial hygiene personnel from the Bremerton Naval Hospital sampled a number of dismantling and maintenance operations and calculated 8-hr TWAs based on the sampling durations. The Bremerton findings are listed in Table 1. Generally, the operations listed are conducted over 6 hour periods. Therefore, the TWAs were recalculated to assume the sampled activity occurred over a 6 hour period in an 8-hr workday (please see the 5th column in Table 1).

TABLE 1
SUMMARY OF OCCUPATIONAL SAMPLING CONDUCTED BY BREMERTON NAVAL HOSPITAL: SUBMARINE DISMANTLING ACTIVITIES

Operation*	Date	Sampling Duration (min)	8 hr TWA (mg/m^3) [a]	8 hr TWA (mg/m^3)[b]	Exceeds PEL (0.5 mg/m^3)
Transformer spill area samples	21-Nov-84	201	0.044	0.079	No
PCB transformer removal	28-Nov-84	134	0.011	0.027	No
Oxy/acetylene torch cutting of <5μg/100cm^2 steel	29-Aug-89	18	<0.0001	<0.002	No
Sweeping & shoveling dry debris from the floor of a (dry) dry dock	4-Oct-89	108	<0.00014	<0.00046	No
Sweeping/shoveling & removing debris from missile compartment of the Ex-SSBN-620	4-Oct-89	124	<0.00024	<0.0007	No
Oxy/fuel torch to cut steel prior to PCB decontamination	4-Oct-89	165	<0.00077	<0.0017	No
Sorting PCB contaminated dirt/small debris (shovels/brooms)	4-Oct-89	211	<0.00034	<0.00058	No
Removing PCB contaminated felt (wire brushes & pneumatic chisels)	4-Oct-89	260	<0.0003	<0.0004	No
Area samples in PCB containing sub where no work was occurring	4-OCt-89	430	<0.00005	<0.00005	No
Welder cutting PCB contaminated steel	14-Jun-90	43	0.009	0.075	No
Area samples inside electrical vault containing PCB filled transformer	5-Sep-90	147	<0.001	<0.002	No
Steel shot blasting of PCB contaminated paint	14-Jan-91	67	0.00155	0.0083	No
Dry sweeping of steel shot to remove PCB contaminated paint from steel (750 ppm PCB dust)	15-Nov-93	138	0.02	0.052	No
Cutting of valves from PCB contaminated pipe with band saw	2-May-94	293	0.015	0.018	No
Crushing (hydraulic press) PCB contaminated ventilation ducting	6-Jun-94	221	0.0013	0.0021	No
Hand scraping to remove missile tube liners after liners were heated to approximately 200° F	20-Jun-94	265	0.02	0.027	No
Cutting PCB contaminated metal plates with large sheer in Bldg. 460	23-Jun-94	193	0.087	0.16	No
Cork insulation attached to paint with PCB (hand scraped)	26-Jul-95	266	0.013	0.018	No

* Breathing zone samples were taken for each operation unless otherwise stated.
[a] 8-hr TWA calculated assuming exposure during the sampling duration and no exposure during the remaining 8 hrs.
[b] 8-hr TWA calculated assuming exposure during 6 out of 8 hrs.

In September 1995, additional personal samples of PCB decontamination operations on submarines at PSNS were collected by the Tri-Service Toxicology's Industrial Hygiene Team from Wright-Patterson Air Force Base. The operations sampled include steel shot blasting, sand blasting, needle gunning, and chipping of felt plates by hand. As part of the dismantling process, decontamination efforts reduce exposure to numerous toxicants. Operations deemed most likely to expose workers to PCBs were selected for sampling.

Decriptions of operations sampled: Steel shot blasting involved the use of steel pellets expelled at high velocities against metal hull surfaces to reduce PCB surface contamination levels to 100 ug/100 cm^2. PCB-containing materials such as paint and/or mastic (insulating material) were removed. The on-hull process was conducted in a contained area inside the decommissioned SSBN John Adams operations section under negative pressure with High Efficiency Particulate Air (HEPA) vacuums. Blast booths were used for off-hull blasting and were equipped with exhaust ventilation consisting of two 260 cubic feet per minute (cfm) HEPA vacuums. Shot was recovered and used again. PPE for blast operators consisted of air supplied blaster's hoods with disposable Tyvex suits over work clothes. Canvas coveralls were worn over Tyvex suits to protect workers from the shot blast. Earplugs, gloves, and booties were also required .

Sand blasting followed the same process except sand was substituted for steel shot. Sand blasting was performed to compare efficiency of paint and/or mastic removal from hulls with steel shot blasting. Sand blasting was conducted at a off-hull (blast booth) site only. A sand recovery sample was collected in addition to blasting samples. Blasting PPE required.

During the needle gunning operation, a gun-shaped tool containing steel rods was used on metal surfaces to remove paint and/or mastic along cut lines (dismantling requires the hull to be cut into frame sections). When the trigger was pressed, high pneumatic pressure forced the steel rods to be pushed rapidly and repeatedly forward and back, pounding the contaminated material off the metal. For on-hull operations, the work area was marked off and self-contained. Off-hull operations were conducted in a blast booth. PPE for needle gun operators consisted of air supplied bubble hoods, disposable coveralls over work clothes, ear plugs, gloves, and booties.

Wire brushes and pneumatic chisels were used to remove dry PCB contaminated felt during the hand chipping operation. This was conducted off-hull in a covered but not contained area. Visible particles were not generated by this procedure and respirators were not worn. PPE worn by workers consisted of disposable coveralls, booties, gloves, and hearing protection.

Sampling protocol: Samples were collected using NIOSH Method #5503 (NIOSH, 1994). Gilian (West Caldwell, NJ) Dual Mode Low Flow air pumps were calibrated to a flow rate of 0.1 to 0.2 L/min dependent on the operation sampled. Sampling train consisted of a disposable Swinnex cassette pre-loaded with a 13 mm glass fiber filter attached to a florisil (100 mg/50 mg) tube. Personal breathing zone samples were collected outside of any PPE

worn by the worker. Pumps were strapped to the back of workers to protect them from flying debris. Sampling trains were taped down over the shoulder of the worker. During blast operations, sampling trains were provided extra taping to protect glass sorbent tubes. Due to the high risk of sample loss, the majority of blast workers were double pumped. Replicates for Quality Assurance/Quality Control (QA/QC) purposes were taken and analyzed for 10% of the samples.

Sampling was conducted in one hour increments for most operations. At the end of the period, the entire sampling outfit was removed and replaced by a new one. Each pump was post-calibrated and decontaminated. Pumps were inspected for impact damage. Filters were removed with tweezers and placed in 7-ml glass vials with teflon-lined caps. Florisil tubes were capped and placed in glass vials. Tweezers were cleaned with methanol. Pumps were charged, as needed, calibrated, and set-up with new sampling train. Samples were packaged, including 2 field blanks per 10 samples, and sent off for analysis.

Analytical protocol: Primary samples were analyzed (Aroclors 1242, 1254, 1260, and 1268) by the Environmental Preventive Medicine Unit Two in Norfolk, Virginia. QA/QC samples were analyzed (Aroclors 1016, 1221, 1232, 1242, 1248, 1254, and 1260) by Clayton Environmental Consultants in Novi, Michigan. The samples were digested with hexane and analyzed by gas chromatography. The detection limit (LOD) specified by the lab for PCB samples was 0.25 ug.

Calculations: Concentrations (C) were calculated for PCBs in the air volume (V) sampled using the following equation:

$$C = \frac{(F + T)}{V}$$

where F is mass on glass fiber filter in ug
T is mass in florisil sorbent tube in ug
V is volume (exposure time X pump calibration) in liters

In the case of nondetects (LOD), it was necessary to estimate the average mass by replacing the nondetectable value (0.25 ug) with LOD/Ö2 (Hornung and Reed, 1990) or 0.177 ug. When both filter and sorbent tube were nondetectable, the total mass assigned for that sample was 0.177 ug. Eight-hour TWAs were calculated for each worker's exposure during the work day using the following equation (National Safety Council, 1988):

$$\text{8-hr TWA} = C_1T_1 + C_2T_2 + \ldots\ldots C_nT_n / 480 \text{ min}$$

where C is the concentration in mg/m^3
T is time of exposure in minutes
n is respective sample periods

Since ug/L (original concentration units) is equivalent to mg/m^3 (8-hr TWA units), no mathematical conversions were necessary. Eight-hour TWAs were calculated for an

average work day exposure of 6 hours. No exposure was assumed during the remaining 2 hours since this time was used to don PPE, remove PPE, and shower. Sampling efforts rarely collected 6 hours of data, thus the average air concentration for sampled periods was used for the unsampled portion of the 6 hour workday.

Sample results: Below are the resulting 8-hr TWAs (see Tables 2 - 4). The detection limit specified by the lab for PCB samples was 0.25 ug. Over 50% of all the filter samples were reported as below the detection limit. All sorbent tubes resulted in nondetects indicating the absence of a vapor phase. Shot blasting was the only operation where sample results exceeded the LOD (Table 2). Aroclors 1254 and 1268 were detected. Since there is no specific PEL for Aroclor 1268, TWAs were compared to the PEL for Aroclor 1254 - chlordiphenyl (54% chlorine). This PEL (0.5 mg/m^3) is the most stringent limit of any PCB mixture listed by OSHA and ACGIH. None of the operations sampled exceeded the OSHA PEL for Arochlor 1254. Replicate samples confirmed these results.

TABLE 2
8-HOUR TWAs FOR STEEL SHOT & SAND BLASTING OPERATIONS

Date	Hull no.	TWA Aroclor 1254 (mg/m^3)[a]	TWA Aroclor 1268 (mg/m^3)[a]	Exceeds PEL (0.5 mg/m^3)?
25-Sep-95	620 (on hull)	0.0115[c]	0.2334	No
25-Sep-95	620 (on hull)	0.0113[c]	0.0113[c]	No
26-Sep-95	620 (on hull)	0.0239[c]	0.0738	No
26-Sep-95	620 (on hull)	0.0262[c]	0.0262[c]	No
27-Sep-95	634 (off hull)	0.023[c]	0.071	No
28-Sep-95	35 (on hull)	0.1724	0.0221[c]	No
28-Sep-95	35 (on hull)	0.241	0.0217[c]	No
28-Sep-95	35 (on hull)	0.3089	0.0221[c]	No
28-Sep-95	658 (off hull)[d]	0.0245[c]	0.0399	No
Average TWA for Blasting [b]		0.0936	0.0579	No

[a] Calculated as a 6 hour blast/8 hour workday.
[b] Average of TWAs for all workers sampled.
[c] TWA calculated on nondetect (LOD) sample.
[d] Sand Blasting sample.

TABLE 3
8-HOUR TWAs FOR NEEDLE GUNNING OPERATIONS

Date	Hull no.	TWA Aroclor 1254 (mg/m^3)[a]	TWA Aroclor 1268 (mg/m^3)[a]	Exceeds PEL (0.5 mg/m^3)?
26-Sep-95	620 (on hull)	0.0129	0.0129	No
26-Sep-95	620 (on hull)	0.0129	0.0129	No
26-Sep-95	620 (on hull)	0.017	0.017	No
26-Sep-95	620 (on hull)	0.0171	0.0171	No
28-Sep-95	658 (off hull)	0.016	0.016	No
28-Sep-95	658 (off hull)	0.0165	0.0165	No
Average TWA for Needle Gunning Operations[b]		0.0154	0.0154	No

[a] Calculated as a 6 hour blast/8 hour workday.
[B] Average of TWAs for all workers sampled.
* All TWAs calculated on nondetect (LOD) samples.

TABLE 4
8-HOUR TWAs FOR HAND CHIPPING OPERATION

Date	Hull no.	TWA Aroclor 1254 (mg/m^3)[a]	TWA Aroclor 1268 (mg/m^3)[a]	Exceeds PEL (0.5 mg/m^3)?
28-Sep-95	641, 620, 663 (off hull)	0.0213	0.0213	No
28-Sep-95	641,633 (off hull)	0.0205	0.0205	No

[a] Calculated as a 6 hour work/8 hour workday. All TWAs calculated on nondetect (LOD) samples.

PSNS sampling conclusions: It can be concluded from these results that worker exposure to PCBs from ship dismantling activities would not exceed permissible limits; however, this would not preclude the use of PPE, including respiratory protection, to protect against other hazards such as particulates, heavy metals (namely lead and chromium), solvents, projectiles, ergonomic stressors and excessive noise. These results support the assumption that any PCB air contamination aboard operational vessels would fall below the LOD. Under normal operational conditions, one would not expect to see higher concentrations of either PCB vapors or particulates with adsorbed PCBs than one would see under dismantling conditions (blasting operations). Area samples collected by Bremerton Naval Hospital in PCB-containing submarines (PSNS) where no operations were occurring also resulted in nondetects. In assessing the risk for an operational, dismantling or maintenance scenario, the LOD would appear to serve as a conservative exposure point concentration. It is important to note that no vapor phase was detected in any of the sample results.

Bulk samples of on-board materials

Solid samples from 78 inactive ships were also statistically analyzed as part of the Navy's effort to evaluate possible personnel exposure to PCBs (NCF #87). This study evaluated the distribution of the PCB solid samples and statistical differences between ships and material types. The analysis was complicated because nearly 50% of the data consisted of non-detects.

Because there were too few data for some ship classes to obtain any reasonable estimates of the population parameters, only the six largest classes were considered. A significant difference was found between four of the six ship classes and between ships within classes as well. From the combined data set, the estimated probability of exceeding 50 ppm was 37.6%, but from class to class this value varied considerably. It should be noted that when the bulk samples were collected, every effort was made to sample from locations likely to have high concentrations of PCBs. If samples were taken from random locations, the concentrations would likely be lower. However, since no random samples were taken, there is no way to determine how much this data tends to overestimate actual exposure levels.

To evaluate the data by material type, the samples were classified into four groups by function: 1) vent gaskets and insulation; 2) wires and cables; 3) bulkhead insulation, and 4) others (See Table 5). The PCB levels were highest for the vent gaskets, with a mean of 34.8 (antilog of 3.55), and lowest for the bulkhead insulation, which had a mean of 0.58 (antilog of 3.55).

TABLE 5
SUMMARY OF SOLID SAMPLE RESULTS CLASSIFIED BY FUNCTION

Material Category	Number < DL	Number > DL	ln Mean (ppm)	Std. Dev.	p
Vent Gaskets /Insulation	285	488	3.55	5.14	0.472
Wires and Cables	194	204	1.97	3.25	0.27
Bulkhead Insulation	134	46	-0.54	4.03	0.13
Other	64	67	1.96	5.16	0.35
Combined	677	805	2.35	4.93	0.38

Notes: DL = Detection Limit (1 μg/g). The data were lognormally transformed.
Adapted from Ross et al., 1993; NCF #87, Appendix 4.

The results from a survey of bulk samples taken from inactive ships performed in 1994 showed similar results (See Table 6) (NCF #1, 1995). Both databases revealed wide variance in PCB concentrations and a large percentage of non-detects. Considering that sampling in both cases was performed to identify likely PCB articles, the percentage of randomly sampled items exceeding the 50 ppm criteria is likely to be much lower than the values indicated.

TABLE 6
INACTIVE SHIPS PCB SURVEY RESULTS - 25 APRIL 1994

Material	Number	No. ≥ 50 ppm	% over 50 ppm	Mean (ppm)	Max (ppm)
Vent gaskets	1363	504	37%	18982	550000
Cable or wire	1666	266	26%	451	240000
Bulkhead Insulation	504	90	18%	616	73000
Vent Insulation	32	2	6%	69	1100
Oil	904	11	1%	9	5000
Rubber Items	330	23	7%	25	3700
Paint	161	14	9%	635	45000
Doubleback Tape	282	31	11%	28	1400

Adapted from NCF #1, Enclosure 18, 1994.

The materials listed in the PSNS database include, but are not limited to, mastic, rubber, arobol, armaflex, felt insulation, electrical insulation, and paints. The method detection limit for the PCB bulk samples reported by the Puget Sound lab was 20 ppm. The Puget Sound lab reported that these LOD were set for compliance purposes with surface contamination and bulk concentration guidelines (10 µg/100 cm^2 and 50 ppm PCB), and are higher than technically achievable. Based upon this information, half of the LOD was used to represent sample concentrations below the LOD. This method is consistent with the treatment for non-detects described in USEPA's Risk Assessment Guidance for Superfund (RAGS) (USEPA, 1989).

Table 7 presents a statistical summary of the bulk samples from PSNS. Outliers were not removed, because without access to original sampling data, it was impossible to judge extreme datapoints as data-entry mistakes or valid values. Unlike typical environmental data, extreme outliers in man-made materials can be expected. The distribution of the data was highly skewed. In most cases, the standard deviation exceeded the mean several times. This was similar to the distributions seen in surface ship data from the NAVSEA files (see Tables 5 and 6)(NCF #1). Review of the results revealed that the median (or 50th percentile) was a much better representation of central tendency and potential exposure levels than the mean.

Felt insulation was found to contain the greatest concentration of PCBs. White foam and arobol, which are also insulating materials, contained lower concentrations. Except for felt, the median values indicated that the majority of the samples fell well below the 50 ppm limit for PCB contamination, as specified in 40 CFR 761. Few samples contained detects of Aroclor 1242 and 1248. The majority of PCBs found on the submarines were Aroclor 1254, 1260 and 1268 mixtures.

TABLE 7
STATISTICAL SUMMARY OF PCB BULK SAMPLES BY MATERIAL TYPE

Material Category	Analyte	N	Mean (ppm)	Std. Dev. (ppm)	Min. (ppm)	Max. (ppm)	Median (ppm)
All bulk samples	Total Ar	7432	560.6	2619.3	10.0	69000.0	28.0
All bulk samples	Ar 1242	130	257.28	2600.0	10.0	30000.0	14.0
All bulk samples	Ar 1248	71	26.22	24.43	4.8	140.0	19.0
All bulk samples	Ar 1254	2307	338.2	1098.0	10.0	36000.0	66.0
All bulk samples	Ar 1260	640	224.0	1242	1.1	26000.0	31.5
All bulk samples	Ar 1268	884	1204.8	4127.95	10.0	35000.0	23.0
Paints	Total Ar	4167	251.7	1394.1	10.0	59000.0	27.0
Electrical Insulation	Total Ar	12	13.6	12.1	10.0	53.0	10.0
Felt	Total Ar	11	27400.1	24357.7	10.0	69000.0	18000.0
Cork	Total Ar	270	230.8	828.0	9.0	6400.0	18.0
Foam (White)	Total Ar	54	1584.0	2991.6	2.0	13000.0	38.0
Armaflex	Total Ar	304	70.7	384.9	10.0	5200.0	12.0
Arobol	Total Ar	223	656.5	2337.3	10.0	24000.0	29.0
Rubber	Total Ar	504	213.7	1617.4	10.0	26000.0	22.5

Notes:
- Ar = Aroclor
- Non-detects were assigned a value of half the LOD, (10 ppm). Therefore, statistical results at or below 10 ppm indicate that the values fall below the LOD.
- Material types, e.g. paint, electrical insulation, etc., are included in the "All bulk samples" category.

Surface swipe samples

Two types of swipe samples were found in the PSNS database, field test kit samples and gas chromatography (GC) analyzed swipe samples. For characterization purposes in this report, only the GC analyzed samples were included in the statistical analysis. The method detection limit of the GC analyzed swipes was 5 µg/100 cm^2.

Table 8 presents a statistical summary of the swipe data from PSNS broken out by submarine component. As with the bulk samples, a large degree of variance was found among the swipes. Again, the median presented the best representation of potential exposure levels. Considerably fewer swipes were analyzed for specific PCB mixture content (e.g., Aroclor 1254 or 1260) than for total PCBs. It appeared that the median surface contamination from Aroclor 1254 was considerably greater than that of total Aroclor in several components. This result was apparently a function of a much smaller sample population for Aroclor 1254.

Although, the toxicity of Aroclor 1254 or 1260 may be of greater concern than the other mixtures detected, it appeared more realistic to use the median total Aroclor levels for evaluating risks from dermal contact with contaminated surfaces. This was due to the limited number of Aroclor 1248 and 1254 samples.

Swipe samples from surfaces of high contact

NAVSEA negotiated an agreement with the USEPA which established PCB management policy on Navy vessels. The agreement specified a cleanup standard for eating and food preparation surfaces, and crew bunks and furniture in offices, medical stations, crew living spaces and recreation quarters of 10 µg/100 cm^2. It specified 100 µg/100 cm^2 in other areas of lower contact. Background PCB levels on such surfaces are expected to be below 10 µg/100 cm^2, although there are no data supporting this assumption.

Using the methodology provided in a USEPA memo entitled "PCB Spill Exposure Scenarios" (Schweer, 1986) NAVSEA calculated the hypothetical carcinogenic risk to a sailor exposed during duty aboard a Navy vessel from exposure to PCB surface levels of 100 µg/100 cm^2. Several conservative assumptions were used in the calculation. The hypothetical risk result was 1.5×10^{-5}, indicating that 100 µg/100 cm^2 is an appropriate level for machinery and space areas in Navy vessels (NCF # 1).

Random swipe samples taken in living areas of operating ships have shown no PCBs above 10 µg/100 cm^2. The sampling effort was concerned only with counter tops in mess decks and galleys, and furniture in crew living spaces and medical stations. The sampling effort did not include decks, overheads, bulkheads or the surfaces of ship machinery or systems (NCF #13).

For comparison, swipe samples from assumed "high contact" areas were selected from the PSNS database and statistically analyzed. Swipe samples taken were selected to represent potential "high contact" surfaces in submarines. The range of concentrations detected are listed in Table 9.

Despite the large range in surface level contamination, the majority of surface swipes taken were below the 10 µg/100 cm^2 level. The probability of contacting surfaces of high concentration appeared to be low.

TABLE 8
STATISTICAL SUMMARY OF PCB SWIPE SAMPLES BY SUBMARINE COMPONENT

Component	Analyte	N	Mean µg/100cm^2	Std Dev. µg/100cm^2	Min. µg/100cm^2	Max. µg/100cm^2	Median µg/100cm^2
Auxiliary Machinery Rm	Total Ar	614	30.8	120.5	2.5	1700.0	2.5
Auxiliary Machinery Rm	Ar 1242	1	9.6	NA	9.6	9.6	9.6
Auxiliary Machinery Rm	Ar 1254	22	136.1	290.5	4.0	1300.0	43.5
Auxiliary Machinery Rm	Ar 1260	67	97.1	231.2	2.5	1700.0	30.0
Auxiliary Machinery Rm	Ar 1268	60	87.5	261	2.5	1400.0	18.0
Bow	Total Ar	130	5.9	16.1	2.5	150.0	2.5
Bow	Ar 1254	5	29.3	39.8	3.4	99.0	11.0
Engine Rm	Total Ar	2003	46.9	257.5	2.5	9900.0	2.5
Engine Rm	Ar 1248	4	60.6	13.3	43.0	75.0	62.5
Engine Rm	Ar 1254	35	342.9	1617.3	1.0	9600.0	24.0
Engine Rm	Ar 1260	258	40.5	68.0	2.5	850.0	19.0
Engine Rm	Ar 1268	413	70.8	575.1	2.0	11000.0	14.0
Main Ballast Tank	Total Ar	398	134.4	745.4	2.5	8100.0	2.5
Main Ballast Tank	Ar 1254	1	15.0	NA	NA	NA	NA
Main Ballast Tank	Ar 1260	21	49.6	54.2	2.5	240.0	38.0
Main Ballast Tank	Ar 1268	20	139.6	508.8	5.8	2300.0	25.0
Missile Rm	Total Ar	531	26.7	64.3	2.5	570.0	2.5
Missile Rm	Ar 1254	13	58.3	58.4	2.7	210.0	35.0
Missile Rm	Ar 1260	36	27.61	32.0	1.9	94.0	12.5
Missile Rm	Ar 1268	52	36.5	55.5	5.1	390.0	23.0
Operations Rm	Total Ar	1240	31.7	159.5	2.5	3300.0	2.5
Operations Rm	Ar 1248	3	28.8	29.9	3.6	62.0	21.0
Operations Rm	Ar 1254	22	625.9	1155.0	5.3	4000.0	129.0
Operations Rm	Ar 1260	83	72.1	113.8	2.0	950.0	52.0
Operations Rm	Ar 1268	74	83.1	204.42	2.5	1500.0	27.0
Sail	Total Ar	46	5.4	13.1	2.5	79.0	2.5
Sonar Control	Total Ar	42	60.7	369.8	2.5	2400.0	2.5
Stern Rm	Total Ar	22	3.1	3.0	2.5	17.0	2.5
Torpedo Rm	Total Ar	179	28.4	141.8	2.5	1600.0	2.5
Torpedo Rm	Ar 1254	7	117.5	130.5	18.0	640.0	35.0
Torpedo Rm	Ar 1260	5	52.4	38.7	23.0	110.0	27.0

Notes:
Ar = Aroclor
Rm = Room
Non-dectects were assigned a value of half of the LOD, which is 2.5 µg/100cm^2. Therefore, statistical results at 2.5 or below indicate the values fall somewhere below the LOD.

TABLE 9
STATISTICAL SUMMARY: SWIPES FROM "HIGH CONTACT" SURFACES (a)

Analyte	N	Mean	Std. Dev.	Min	Max	Median	Q1	Q3
Total Ar	3698	52	326	0	9500	3	3	32
Ar-1242	4	7	5	4	14	6	4	12
Ar-1248	8	15	30	2	89	4	2	8
Ar-1254	75	11	14	2	82	5	3	13
Ar-1260	593	50	296	1	4000	7	3	16
Ar-1268	690	46	453	0	11000	6	3	12

Ar = Aroclor
Q1 = 25th Percentile
Q3 = 75th Percentile
(a) = High contact areas; swipes taken below 8 ft.

Electrical cables aboard Navy vessels (swipe and bulk samples)

Some electrical cables on older ships and submarines may contain PCBs as a result of former manufacturing processes. In August of 1992, the Navy undertook an extensive program to determine if cables containing PCBs in excess of 50 ppm presented an unreasonable risk to health or the environment if left in place aboard US Navy vessels (NCF #87). The program used the resources of several laboratories, including those at Norfolk Naval Shipyard, PSNS, Naval Surface Warfare Center-Annapolis Detachment and Naval Research Laboratory. The program spanned a range of topics from sampling and analysis of PCBs on the surfaces of shipboard cables to laboratory investigation of the mobility of bulk PCBs from internal cable components to the cable surface. In total, 398 bulk and wipe samples representing 72 ships in 31 classes were used in the analysis.

In brief, the data showed that: 1) while some shipboard cables contained PCBs in excess of 5000 ppm, 95% contained less than 500 ppm and over 72% contained less than 50 ppm PCBs; 2) the probability of finding PCBs on a cable surface in excess of 10 $\mu g/100\ cm^2$ was extremely low (less than 0.63%) and there was a 0.09% probability of a cable surface exceeding 100 $\mu g/100\ cm^2$; 3) there was no correlation between bulk and surface PCB levels, and 4) the mobility of PCBs from internal cable components to the cable surface was negligible.

Because the sampling protocol used in these studies was designed to locate PCBs at high concentrations and the ships sampled represented some of the oldest in the fleet, the results constituted a worst case description of PCB contamination of shipboard electrical cable surfaces. Even though the results were conservatively biased and do not represent valid probability of exposure, the results did indicate minimal risk to personnel or environment due to exposure from PCBs associated with the continued use of Navy

ship cables. If a random sampling had been taken, the probability of exceeding of 50 ppm would have been considerably lower.

The Navy also performed studies to determine if certain conditions to which shipboard cables might be exposed could cause the diffusion of PCBs to the cable surface (NCF #87). Seven cables from the decommissioned USS Queenfish with detectable surface levels of PCBs were used. The armor sheath of each cable was removed before the initial surface wipes were collected and treatments applied. Three treatments were evaluated: 1) three cables were subjected to 200°F for 48 hours; 2) three cables were coated with a film of hydraulic and lubricating oil (2190 TEP) and subjected to 140°F for 24 hours, and 3) one cable was subjected to a pressure corresponding to 6000 feet of sea water for 24 hours.

A comparison of the results indicated that PCB levels after treatment were either equal to or slightly less than prior to treatment. Also, the distribution of PCB congeners measured was the same in the before and after treatment swipes, demonstrating that the treatments did not degrade or selectively extract PCB congeners. There was no statistical correlation between the bulk and surface PCB levels in the cable samples. In addition, PSNS acquired further ship and submarine cable bulk and surface PCB-contamination data supporting the conclusion that there was no correlation between cable bulk and surface levels (NCF #87).

These results indicated that the selected treatments did not increase the concentrations of PCBs on the cable surface. After many years of service and abusive treatments, the PCBs in the cable components remained in-place. Therefore, continued use of Navy cable is unlikely to pose a risk of exposure to personnel or the environment.

The use of swipe samples to indicate PCB concentration or exposure is highly uncertain. The USEPA is assuming that a PCB article with <100 $\mu g/100\ cm^2$ constitutes a PCB-contaminated article (>50 ppm and <500 ppm PCBs), and >100 $\mu g/100\ cm^2$ constitutes a PCB article (>500 ppm). There is no documentation to show that PCB content can be predicted on the basis of wipe test results. In addition, wipe samples are taken using a hexane saturated cotton swab, which would be expected to extract PCBs even from bound matrixes. Swipe sampling does not indicate the amount of PCBs that would transfer to the skin upon contact.

Bulk samples have shown PCB levels above the USEPA advisory level of 50 ppm in approximately 24% of all cables removed from Navy vessels and crafts (NCF #3). However, PCBs in cable do not pose a direct hazard to personnel or the environment. The PCBs are tightly bound in the plastic, are not released when the cable is cut and do not migrate to the surface. Therefore, they cannot be ingested. PCBs in cables are non-liquid; they do not evaporate and do not present an airborne exposure risk under normal operating or dismantling conditions.

Variations in PCB surface concentrations from the same article have been noted with varying wipe techniques. For example, the Navy subjected one cable sample to

repeated surface swipe sampling. The first surface swipe was taken before the armor sheath was removed; all subsequent swipes were taken from insulation material immediately under the sheath. The initial cable surface swipe with the armor sheath intact yielded a PCB level below detection (<1 μg/100 cm^2). Three subsequent surface swipes of the insulation (rubber) material all showed the same quantity of PCBs (8 μg/100 cm^2). Two additional surface swipes were taken with less pressure and the cable surfaces were only wiped once (versus twice before). Both of these samples showed approximately 2 μg/100 cm^2 PCBs (NCF #87). These results suggest that the wiping process can extract PCBs from materials. In addition, the amount of PCBs sampled from a cable surface using the swipe procedure will depend upon exactly how the surface is wiped.

TCLP

At NAVSEA's request, PSNS collected samples of typical shipboard materials known to contain PCBs in excess of 50 ppm. These materials included wool felt sound damping material, Ensolite™ rigid foam insulation, rubber gaskets, paint and electrical cable jacketing. These materials were tested for leachability characteristics. The samples were collected from materials previously analyzed in accordance with USEPA Method 8080 and found to contain PCBs, generally in excess of 50 ppm. The results of the analyses showed that the materials, with the exception of the wool felt, leach less than the limit of 50 μg PCBs/L as would be specified in the proposed rule (see Table 10). The felt material, given its high PCB content, leached a remarkably small amount, but the leachate was in excess of the proposed limit. It is likely that the felt's wool fibers have a higher affinity for the TCLP solvent than for the PCBs, causing a small percentage of the PCBs to be freed.

Surface wipes of these materials showed that the PCBs are not mobile and remained fixed in the material (NCF #1). Although additional testing could be conducted, all results to date support this conclusion. The PCBs are contained within the matrix of the non-felt materials, do not migrate to the surface, and would not be expected to leach PCBs in excess of the proposed TCLP limit of 50 ppb.

Available PCB, PCDF and PCDD data from a submarine fire

Air, water, and surface (swipes and core) samples were taken from the USS Thomas A. Edison (USS 610) in 1990 after a fire occurred on the defueled and inactivated submarine while it was in dry-dock. PCB bearing materials were known to exist in thermal insulation, electrical cable and rubber items located in the fire area. The samples were analyzed for PCBs and related combustion products, namely PCDFs and PCDDs. Listed below is a summary of the data (PSNS, 1990).

TABLE 10
TCLP RESULTS FROM SHIPBOARD MATERIALS

Ship Hull Number / Location	Material Type	PCB Content (ppm)	TCLP (μg PCB/l)
SSN634 / Missile Compartment	Felt	110,000	57
SSN641 / Missile Compartment	Felt	110,000	65
SSN662 / Torpedo Room	Ensolite	1,300	<1.0
SSN662 / Operations	Ensolite	13,000	<1.0
SSN657 / Missile Compartment	Rubber	260	<1.0
SSN657 / Missile Compartment	Rubber	96	<1.0
SSN584	Electrical Cable	32,000	<1.0
SSN656	Electrical Cable	250	<1.0
SSN656	Electrical Cable	950	<1.0
SSN656	Electrical Cable	<20	<1.0
SSN634 / Torpedo Room	Paint	63	<1.0
SSN634 / Missile Compartment	Paint	86	<1.0
SSN634 / Operations	Paint	72	<1.0
SSN641 / Operations	Paint	10,000	4.8
SSN641 / Missile Compartment	Paint	1,500	<1.0
SSN641 / Aux. Machine Room	Paint	100	<1.0
SSN650 / Operations	Paint	140	<1.0
SSN663 / Bow Compartment	Paint	3,000	<1.0
SSN663 / Bow Compartment	Paint	280	<1.0
SSN663 / Engine Room	Paint	700	<1.0

Adapted from T. Pape, 1995; NCF #1, Enclosure 5.

Air samples

- Nine air samples were taken before the fire occurred. No radioactivity was detected and the PCB levels were all less than the OSHA PEL of 0.5 mg/m^3.
- During the fire, when the smoke plume was at its peak, one air sample was taken using the NIOSH protocol; the sample result was 0.0018 mg PCB/m^3.
- After the fire, four samples were taken inside the boat, in the fire area. The PCB levels detected in these samples were found to be 0.0045 mg/m^3 or less.

Water samples

- Samples were gathered from a pool inside the boat created by water used to fight the fire. One sample taken from the surface of the pool resulted in 619 ppb. Another sample taken from below the surface resulted in 18 ppb.
- Water dripping from the hull was measured at 9 ppb.
- Twelve samples from dry-dock discharge inlets were mostly Non-Detects (NDs); two measured 2 ppb. Two samples from the pump wells measured at 38 and 120 ppb.
- Any concentration detected was above USEPA's current discharge limit of none.

Surface samples

- Swipe samples taken of the dry-dock in the path of the smoke plume were all NDs.
- Nine core samples from the dry dock concrete floor were between 1.2 and 1.5 ppm; seven samples were NDs.
- All external ship samples fell below USEPA's limit of 25 ppm for restricted access areas.
- Swipe samples for PCBs from areas within the ship showed readings from ND to 430 μg/100 cm^2.

PCDD samples

- All PCB swipe samples on external surfaces of the ship were ND for PCDDs.
- Seven soot samples from inside the ship showed PCDD levels ranged from 0.64 to 24.6 ng/100 cm^2. This level of PCDD contamination was considered extremely low.
- PCB cleaning methods were determined adequate for the clean-up of any PCB-generated PCDDs.
- A swipe sample from a fireman's hat gave a positive finding of 53 μg PCB and 5.4 ng PCDD-equivalent per 100 cm^2.

In addition, medical monitoring was conducted on all personnel with potential PCB exposure from either the fire or cleanup beginning the day after the fire and continuing through the next six days. Blood samples were analyzed for PCB content. The average blood concentration detected among the 135 individuals with the greatest probability of exposure was 2.61 ppb; the maximum detected concentration was 8.9 ppb. The mean serum concentration in the non-occupationally exposed population in the US has been found to be between 4 and 8 ppb, with 95% of the population having serum PCB concentrations less than 20 ppb (Kreiss, 1985). Therefore, the PCB serum levels were well within the ranges found in non-occupationally exposed populations.

This data indicated that no significant release of PCBs or PCDDs/PCDFs to the environment occurred as a result of the fire. This data also suggested that a significant exposure to these contaminants would not likely result from hot work (involving cutting metals with torches or welding) performed under controlled conditions protective of the workers health. It is noted that cut lines are cleaned to 100 μg/100 cm^2 prior to cutting and workers use appropriate PPE, including supplied air.

Background levels of PCBs

The following paragraphs present ambient levels of PCBs in air, water, soil and foodstuff that have been reported in recent literature. There is little background information on PCB levels in typical construction materials or occupational environments outside of the PCB manufacturing industries.

Because of their wide-spread use, high persistence and other physical and chemical properties, PCBs are ubiquitous throughout the environment all over the world. Due to their lipophilic properties, PCBs readily bioaccumulate and are almost universally present in organisms in the environment. Biomagnification in food chains has also been demonstrated. The more highly chlorinated congeners accumulate preferentially.

Air

Globally, PCBs are found in air concentrations from 0.002 to 15 ng/m^3. In industrial areas, levels can be as high as 30 ng/m^3 (ATSDR, 1993.) In general, air levels over industrial areas or landfills are the highest. Air concentrations have a direct effect on PCB levels in rain water and snow. PCBs in rain and snow are found in the range of 1 to 250 ng/L (ASTDR, 1993).

Under indoor occupational conditions, the levels in the air may be much higher. For instance, in the manufacturing of transformers or capacitors, levels of up to 1 mg/m^3 have been observed (World Health Organization (WHO), 1993). In acute emergencies, concentrations of up to 16 mg/m^3 have been measured (WHO, 1993). Through fires and/or explosions, soot has been produced that contains levels of 8000 mg PCB/kg soot. In the latter situation, PCDFs may also be present. PCDDs may be found in fire accidents with transformers containing simple chlorinated benzenes and PCBs.

Of interest for comparing airborne levels on operating submarines to background levels are those values reported in the literature for indoor office buildings and residential settings. MacLeod (1981) estimated the presence of PCBs in workplaces and homes in the US. Three facilities, an industrial research facility, an academic facility, and a shopping complex were sampled. Periods of sampling ranged from two days to six months. It was found that the median indoor air concentration of PCBs was at least one order of magnitude higher than that in the surrounding outdoor air. The average indoor air concentrations (calculated as Aroclor 1242 plus Aroclor 1254) ranged from 44 to 240 ng/m^3. Outdoor levels of up to 18 ng/mg^3 were found. Several homes were also sampled. In the homes, 9 out of 14 areas sampled were kitchens. The average concentrations in kitchens ranged from 150 up to 500 ng/m^3 and, in other rooms, from 39 to 170 ng/m^3. In one library, a level of 400 ng/m^3 was detected. It has been suggested that certain electrical appliances and devices (such as fluorescent lighting ballasts) and building materials (elastic sealant), which have PCB-containing components, may emit PCBs into the indoor air, thereby elevating indoor PCB levels significantly above outdoor background levels (Balfanz et al., 1993).

Oatman and Roy (1986) studied PCB exposure levels in public buildings in Minnesota. Air samples and surface wipe samples taken in five state-owned office buildings and two elementary schools were analyzed for Aroclor 1242, 1254, and 1260. The average airborne levels in buildings with PCB transformers were nearly twice the levels in buildings without transformers containing PCBs, (i.e., 457 ± 223 versus 229 ±

106 ng/m^3, respectively). The mean concentration of surface wipes taken in buildings without PCB transformers was 0.17 μg/100 cm^2; the mean of wipes taken in buildings with PCB transformers was 0.23 μg/100 cm^2. As shown above, there was wide variation in air concentrations between different buildings; however, the air concentrations were significantly affected by the presence of PCB containing transformers. Unlike this data, the lack of detetion of air concentrations of PCBs aboard Navy vessels during normal operations agin suggest that the PCBs are bound.

Water

Surface water may be contaminated by PCBs from atmospheric fallout, direct emissions from point sources, or waste disposal. Because of adsorption on suspended particles, PCB concentrations in heavily contaminated waters may be several times greater than the solubility of PCB would deem feasible. When sediment is allowed to settle out of a water column, PCBs are generally no longer above the detection limit.

The concentrations of PCBs in large open water masses such as the oceans and Great Lakes provide useful information for establishing background levels in water. The total concentration of 82 congeners of PCB in water from Lake Superior decreased to a value of 0.18 ng/L in 1992 from its value of 2.4 ng/L in 1980 (Jeremiason et al., 1994), reflecting the diminishing levels of background PCBs in the environment since the discontinuation of their use. The mean concentration in Lake Michigan was 1.8 ng/L, with concentrations higher in near-shore samples (mean of 3.2 ng/L) than in open lake samples (mean of 1.2 ng/L). In polluted waters in the Netherlands and the coastal Lake Michigan area, levels of 100 to 500 ng/L water have been measured (WHO, 1993). In non-polluted fresh waters of North America, fresh waters might contain less than 5 ng/L (WHO/EURO, 1988). In the oceans, levels of 0.05 to 0.6 ng/L have been found. (WHO, 1993)

PCBs have been found in surface waters throughout the world. In non-contaminated areas, drinking water contains less than 1 ng PCBs/L, but levels of up to 5 ng/L have been reported (WHO, 1993). Filtration is very effective in reducing PCB levels in water.

Soil and Sediment

Soil and sediment in several unpolluted areas contain levels of PCBs ranging from less than 0.01 up to 2.0 mg/kg. In industrialized areas, the levels detected are much higher (i.e., up to 500 mg/kg) (WHO, 1993).

Food

In past years, many thousands of samples of different foodstuffs have been analyzed in several countries for contaminants including PCBs. Most samples have been taken from individual food items, especially fish, meat and milk. Human food has become contaminated with PCBs by three main routes:

- Uptake from the environment by fish, birds, livestock (via food chain) and crops,
- Migration from packaging materials into food (mainly below 1 mg/kg but, in some cases, up to 10 mg/kg), and
- Direct contamination of food or animal feed by an industrial accident.

The levels for the most important PCB-containing food items were: animal fat (20-240 μg/kg), cow's milk (5-200 μg/kg), butter (30-80 μg/kg) and fish (10-500 μg/kg), on a fat basis. These are the major foods in which PCB contamination needs consideration. Vegetables, cereals, fruits, and a number of other products contained levels of less than 10 μg/kg. It appears that PCB levels in fish and animal foodstuffs are slowly decreasing (WHO, 1993).

On the basis of the evaluated backgroung data, the adult average dietary intake of PCBs amounts to a maximum of 100 μg per week or approximately 14 μg/person-day. For a 70 kg person, this is an intake of 0.2 μg/kg body weight-day (WHO/EURO, 1988).

RISK CHARACTERIZATION

Two exposure pathways were identified as potential risk to workers, inhalation and dermal exposure. However, no vapor phase was detected during dismantling operations (cleaning of ventilation systems and at-sea operations) and appropriate PPE was used to prevent exposure to particulates. Therefore, inhalation is not a pathway of concern and no further action is required beyond the standard workplace monitoring. The issue of potential dermal exposure to solid or bound PCBs versus liquid raises the question of transfer and absorption. A probabilistic risk assessment on crew members and shipyard maintenance workers, the two cases where dermal exposure is most likely, was performed using Crystal Ball® (Decision Engineering, Denver CO, 1993). In this approach, a distribution of data rather than a single data point is used to represent key exposure variables. A range of results are then calculated.

For active duty crew members the distributions listed in Table 11 were used in the risk calculation. It was assumed the only dermal area to be in contact with painted surfaces and gaskets were the hands and forearms. The frequency of exposure was estimated to be 30 minutes each day. While sleeping, eating and at a workstation the crew members would not be contacting any surface which may contain PCBs. The limited exception would include any repair activities. Those would then be considered maintenance and the frequency would not apply for the entire time that individual would be aboard the submarine or ship. The days per year onboard ship is estimated to range from 180 to 335 days with a point estimate of 10 months or 305 days.

For shipyard workers it was also assumed that only the forearms would be exposed to PCB-containing materials. During dismantling activities these workers wear PPE. However, a worst case scenario was assumed to cover periods when general maintanance and repairs are conducted and PPE may not be worn . During maintanance and repair workers may contact materials of high concentrations such as felt damping or rubber caskets.

The representative distribution of swipe concentrations that active crew members may be exposed to included only samples from submarine compartments where work is normally conducted, i.e. the engine room, auxillary machine room, operation room, sonar room, etc. This was done to ensure that concentrations from inner hull or materials inaccesssible during normal operations would not be included in the analysis. Materials such as PCB saturated felt damping and other insulating materials highly skew the concentration distributions and would result in overestimation of risk by two or more orders of magnitude. In the risk calculation one half of the detection limit was used in the case of NDs and 5 percent of the outliers were removed.

TABLE 11
EXPOSURE FACTOR ASSUMPTIONS

Factor	Distribution Type	Range	Means or most likely value	Basis
c = swipe concentration PCB onboard	lognormal	ND - 80 μg/100 cm^2 stdev = 15.4	8.41 μg/100 cm^2	PSNS PCB database
c = swipe concentration PCB from dismantled materials	lognormal	ND - 590 μg/100 cm^2 stdev = 56.6	29.07μg/100 cm^2	PSNS PCB database
sa = surface area contacted (arms/hands)	triangular	1690 - 4050 cm^2/day	3120 cm^2/day	surface area of hands and foreams (Versar, Inc. 1991)
t = transfer factor	triangular	1 - 25%	10%	Hammerstram, 1986
a = dermal absorption	triangular	12 - 44%	30%	Wester et. al. 1993
d = duration (active crew)	triangular	2 - 20 yr	8 yr	Navy communication
d = duration (shipyard workers)	triangular	1- 20 yr	2 yr	Navy communication
cf = conversion factor	NA	NA	0.001 mg/ug	NA
f = frequency of exposure (active crew)	triangular	3.75 - 6.98 d/yr	6.35 d/yr	30 minute exposure per day while onboard 180 - 335 d/yr with the mean at 305 d/yr
f = frequency of exposure (shipyard workers)	triangular	22.5-64.8 d/yr	31.3 d/yr	6 hr/day on dismantling projects, from 90 to 250 d/tyr with the mean of 6 hr/d for 125 d/yr
bw = body weight	lognormal	46-143 kg stdev = 12.2	Mean = 81 kg	Flemming et al., 1996
at = lifetime averaging time	-	-	25,550 d	Based upon a 70 yr lifetime.(USEPA, 1989)

NA= not applicable, ND = nondetects, stdev = standard deviation

The distribuition used to represent shipyard workers included the entire database, with 5 percent of the outliers removed. NDs were again assigned one half the detection limit (2.5 ug/cm^2). This population is more likely to contact materials with high PCB concentrations during dismantling activities. Because the PSNS PCB database compiles the results from various types of materials sampled, several of which are not identified in the database, very large variance was expected.

Body weight was derived from an extensive survey of Navy fleet members (Flemming et al., 1996). It is believed that this distribution better represents Naval submariners than body weight distributions from the general population. Body weight and total skin surface area are strongly correlated. Phillips et al. (1993) reported a correlation coefficient of 0.986 from a data set of 401 adults, indicating that surface area is dependent on body weight. This study did not develop correlation between surface area to body weight for specific parts of the human body. A literature search did not reveal any such studies, however the correlation between body weight and the surface area of the forearms and hands is not expected to be as high due to the presence of less fat on the extremites. Therefore, a correlation of 0.75 was assumed between body weight and surface area of the hands and forearms. The actual correlation is likely to be higher. Assuming a correlation of 0.75 is conservative and reduces uncertainty.

Distributions of several parameters were not available, such as absorption, frequence and duration. In situations where the minimum, maximum and 'most likely to occur' values were known, triangular distributions were assigned. Lifetime Average Daily Dose (LADD) is calculated using the equation below and the parameters listed in Table 11.

$$LADD = \frac{c \times sa \times t \times a \times d \times f \times cf}{bw \times at}$$

The LADD is then multiplied by a cancer slope factor to calculate a risk level. A detailed description of each of the assumptions, including the distribution data of each probability distribution used in the model are provided in Appendix A.

The recent USEPA approach to PCB dose-response assessment recommends a tiered approach to quantify risk from persistent PCB contamination (USEPA, 1996). A range from a central slope to an upper-bound slope is assigned to three tiers of potential risk. The upper bound slope (2 mg/kg-d $^{-1}$) of the high risk tier was used in assessing dermal risk. The high risk level is applied in cases using an absorption factor and also accounts for dioxin-like congeners which may be present in the media. If intake is not adjusted with an absorption factor, USEPA recommends using the central slope (0.3 mg/kg-d^{-1}) for the low risk and persistence tier. For this risk assessment, a uniform distribution between 0.3 and 2.0 mg/kg^{-1} was used.

The resulting frequency distributions of risk to both the active crew and the shipyard workers are shown in Figures 2 and 3, respectively. The forecasted risk from dermal exposure to both the active crew members are the shipyard workers are at acceptable levels.

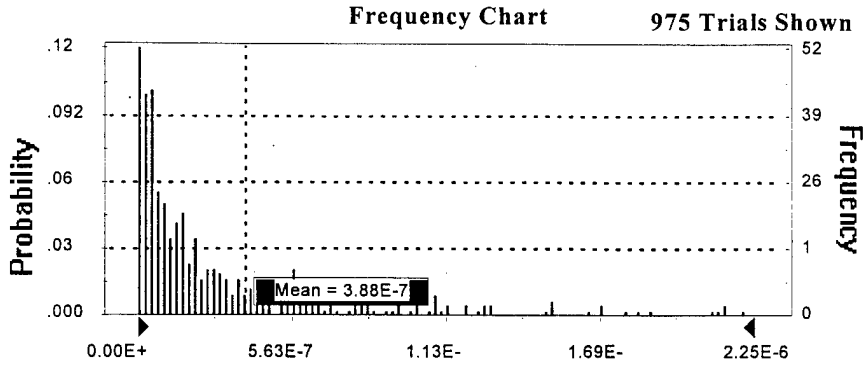


Figure 2. Forecast: Risk to Active Crew

The entire simulated range of risk to the active crew is from 2.26E-9 to 6.65E-6. After 975 Trials, the standard error of the mean is 3.56E-8. The 90 percentile is 9.77E-7. Therefore, the risk to the active crews from dermal uptake of PCBs is insignificant and does not warrant further investigation or mitigation to reduce exposure. The statistics of the forcast are listed in Appendix B.

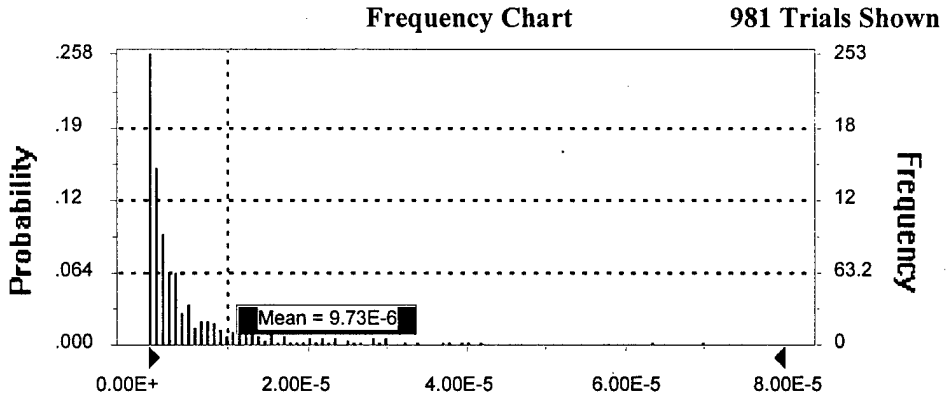


Figure 3. Forecast: Risk to Shipyard Workers

Risks to the shipyard workers were slightly higher due to a higher exposure concentration and contact rate. The entire range is from 1.08E-8 to 3.82E-4. After 1000 trials, the standard error of the mean is 8.03E-7 and the mean is 9.73E-6 (Figure 3). The 90th percentile is at a risk level of 2.31E-5, well within acceptable levels. A summary of the forecast statistics is provided in Appendix B.

This distribution of risk incorporates the assumption that shipyard workers will directly contact any PCB-containing material on the submarines during dismantling

activities. These results represent a worse case scenario. In actuality, the workers wear PPE and the dermal pathway is unlikely if not eliminated completely.

Sensitivity analysis allows judgment of those assumptions which have the most influence on risk. During each simulation, the assumptions are ranked according to their correlation to the forecast result. The assumptions with the highest ranked correlation can be considered the most important factors in the model.

The results of the sensitivity analysis performed on the risk calculations are presented in Figure 4. The exposure parameter contributing the greatest variance to risk is surface concentration. The measured ranked correlations for surface concentration and transfer factor were 0.75 and 0.41, respectively. This was expected at the onset of the assessment, given the highly skewed distribution of collected PCB swipe data. The parameter contributing the second highest amount of uncertainty is the transfer rate of PCBs from the various media to the skin. Consistent data on this factor was not available at the time of the analysis. The assigned triangular distribution, ranging from 0 to 50% with a most likely value of 10% (see Table 12 and Appendix A), represents a very conservative assumption which impacts uncertainty in the direction of overestimation.

Data regarding the variability of transfer rates from different media is not available. The swipe samples were taken using hexane soaked gauze which is likely to result in significantly higher levels than samples collected without a solvent. As discussed earlier, it has been demonstrated that the variation in pressure applied while conducting swipe sampling will result in varying surface concentrations.

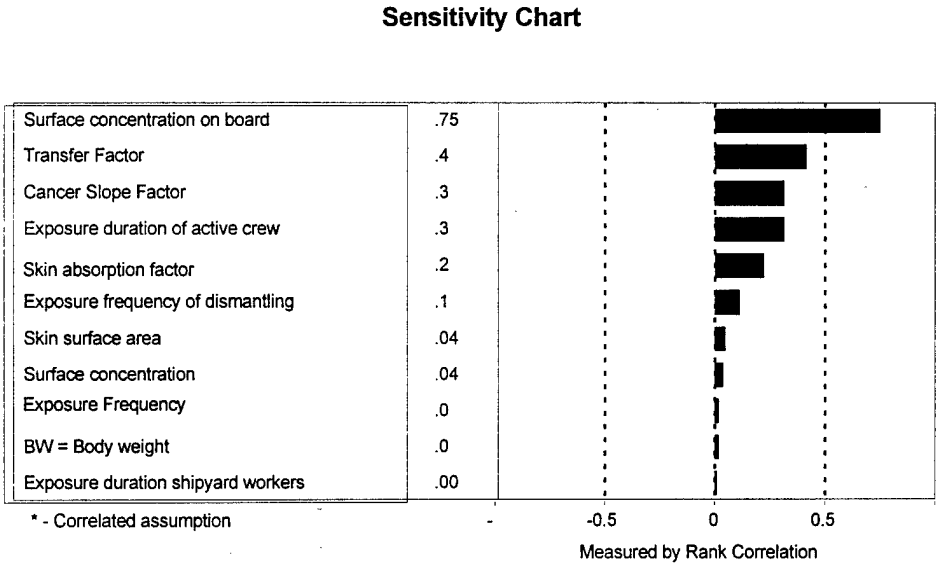


Figure 4. Target Forecast: Risk to Active Crew

RECOMMENDATIONS

Based upon the information gathered a number of recommendations have been identified which would be useful for reducing the uncertainties in the human health risk assessment. Many of these recommendations address the lack of specific data for assessing exposures. Other recommendations identify additional research needs. The following paragraphs discuss these needs and recommendations in further detail.

Relevant exposure information

The air and wipe sample data, provided from the NAVSEA Copy File and PSNS have indicated that air concentrations under most operational and dismantling conditions remain below detection limits. Westinghouse Material Technology Development has additional information regarding work-time studies on these vessels for establishing "real world" exposure scenarios and information regarding characterization data. This information could increase the data base for the risk assessment and should be included.

A toxicity assessment of the Aroclor 1268 mixture

A number of literature searches on Aroclor 1268 toxicity and its congener breakdown have resulted in very limited information. Aroclor 1268 has been detected throughout Navy submarines and surface ships. Studies have shown increasing toxicity of PCBs with increased chlorine content up to 60% and possible decreasing toxicity above 60%. Dose response and toxicity information on Aroclor 1268 would be useful in assessing its risks inconjunction with Navy vessels.

An assessment of transfer factors and dermal absorption rates of PCBs

Dermal absorption appears to be a significant exposure route for liquid but not for solid PCBs. Dermal contact to PCBs in Navy submarines and surface ships would primarily involve contact with a PCB-containing material (e.g., paint and insulating materials). In such cases, the PCBs are bound in solid phase. Transfer rates for determining bioavailability from these materials have not been determined; however, the results of TCLP tests suggest PCBs are not highly mobile. In addition, dermal absorption rates of PCBs have been reported to range from approximately 1% using a soil dosing media, to 44% using water as the dosing vehicle (Wester et al., 1993).

Conclusion

These gaps increase the uncertainty and tend to overestimate the potential risk in the final assessment. Human data in the literature are of limited value, since PCB exposures were mixtures, specific aroclors were frequently not identified and specific congeners were never identified. The results of sampling and data review indicated that with proper engineering controls dioxins (PCDDs) and furans (PCDFs) are not a concern during dismantling and an inhalation exposure pathway is not significant. Navy studies to date show that PCBs remain bound in the cable and paints and the potential for dermal exposure does not appear to be a significant pathway.

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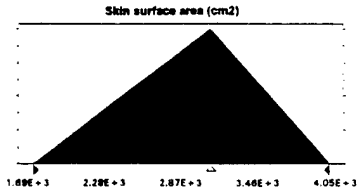
APPENDIX A

Assumptions Used in Probabilistic Risk Assessment

Assumption: Skin surface area (cm^2)

Triangular distribution with parameters:

Minimum	1.69E+03
Most likely	3.12E+03
Maximum	4.05E+03



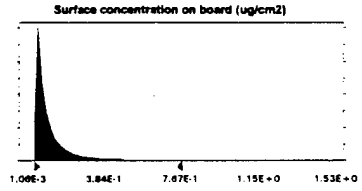
Selected range is from 1.69E+3 to 4.05E+3
Mean value in simulation was 2.99E+3

Correlated with:
BW = Body weight (kg) 0.75

Assumption: Surface concentration on board (ug/cm^2)

Lognormal distribution with parameters:

Mean	8.41E-02
Standard Dev.	1.54E-01

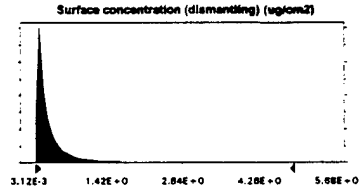


Selected range is from 0.00E+0 to 7.73E-1
Mean value in simulation was 7.34E-2

Assumption: Surface concentration (dismantling) (ug/cm^2)

Lognormal distribution with parameters:

Mean	2.91E-01
Standard Dev.	5.66E-01



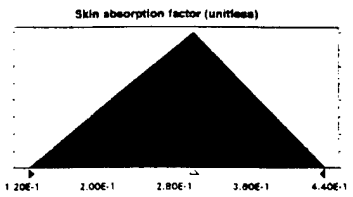
Selected range is from 0.00E+0 to 5.00E+0
Mean value in simulation was 3.03E-1

Assumption: Skin absorption factor (unitless)

Triangular distribution with parameters:

Minimum	1.20E-01
Most likely	3.00E-01
Maximum	4.40E-01

Selected range is from 1.20E-1 to 4.40E-1
Mean value in simulation was 2.87E-1

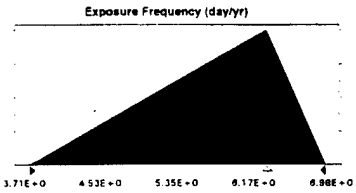


Assumption: Exposure Frequency (day/yr)

Triangular distribution with parameters:

Minimum	3.71E+00
Most likely	6.35E+00
Maximum	6.98E+00

Selected range is from 3.71E+0 to 6.98E+0
Mean value in simulation was 5.69E+0



Assumption: BW = Body weight (kg)

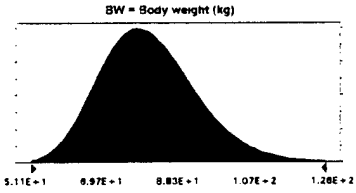
Lognormal distribution with parameters:

Mean	8.10E+01
Standard Dev.	1.22E+01

Selected range is from 4.60E+1 to 1.43E+2
Mean value in simulation was 8.10E+1

Correlated with:

Skin surface area (cm^2) 0.75

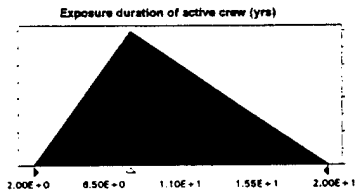


Assumption: Exposure duration of active crew (yrs)

Triangular distribution with parameters:

Minimum	2.00E+00
Most likely	8.00E+00
Maximum	2.00E+01

Selected range is from 2.00E+0 to 2.00E+1
Mean value in simulation was 1.00E+1

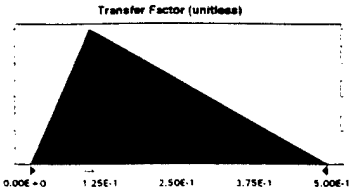


Assumption: Transfer Factor (unitless)

Triangular distribution with parameters:

Minimum	0.00E+00
Most likely	1.00E-01
Maximum	5.00E-01

Selected range is from 0.00E+0 to 5.00E-1
Mean value in simulation was 2.01E-1

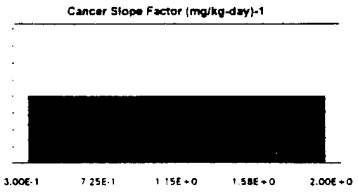


Assumption: Cancer Slope Factor (mg/kg-day)$^{-1}$

Uniform distribution with parameters:

Minimum	3.00E-01
Maximum	2.00E+00

Mean value in simulation was 1.16E+0

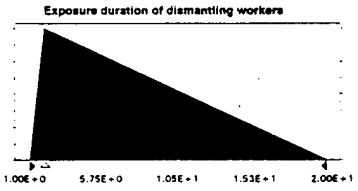


Assumption: Exposure duration of dismantling workers

Triangular distribution with parameters:

Minimum	1.00E+00
Mostl likely	2.00E+00
Maximum	2.00E+01

Selected range is from 1.00E+0 to 2.00E+1
Mean value in simulation was 7.56E+0

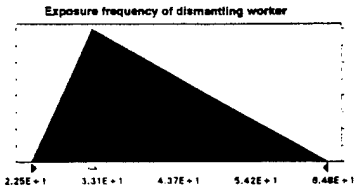


Assumption: Exposure frequency of dismantling worker

Triangular distribution with parameters:

Minimum	2.25E+01
Most likely	3.13E+01
Maximum	6.48E+01

Selected range is from 2.25E+1 to 6.48E+1
Mean value in simulation was 4.00E+1



APPENDIX B

Risk Characterization Forecast Statistics

Statistics of risk to Active Crew	Value
Trials	975
Mean	3.88E-07
Median (approx.)	1.57E-07
Mode (approx.)	3.55E-08
Standard Deviation	6.93E-07
Variance	4.80E-13
Skewness	4.70E+00
Kurtosis	3.35E+01
Coeff. of Variability	1.79E+00
Range Minimum	2.26E-09
Range Maximum	6.65E-06
Range Width	6.65E-06
Mean Std. Error	3.32E-08

Percentile	Risk Level (approx.)
0%	2.26E-09
10%	1.96E-08
20%	4.17E-08
30%	6.37E-08
40%	1.01E-07
50%	1.57E-07
60%	2.21E-07
70%	3.43E-07
80%	5.45E-07
90%	9.77E-07
100%	6.65E-06

Statistics of risk to the Shipyard Workers:	Value
Trials	1000
Mean	9.73E-06
Median (approx.)	2.39E-06
Mode (approx.)	1.92E-06
Standard Deviation	2.54E-05
Variance	6.45E-10
Skewness	7.12E+00
Kurtosis	7.36E+01
Coeff. of Variability	2.61E+00
Range Minimum	1.08E-08
Range Maximum	3.82E-04
Range Width	3.82E-04
Mean Std. Error	8.03E-07

Percentile	Risk Level (approx.)
0%	1.08E-08
10%	3.62E-07
20%	7.14E-07
30%	1.07E-06
40%	1.59E-06
50%	2.39E-06
60%	3.65E-06
70%	6.09E-06
80%	1.09E-05
90%	2.31E-05
100%	3.82E-04

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